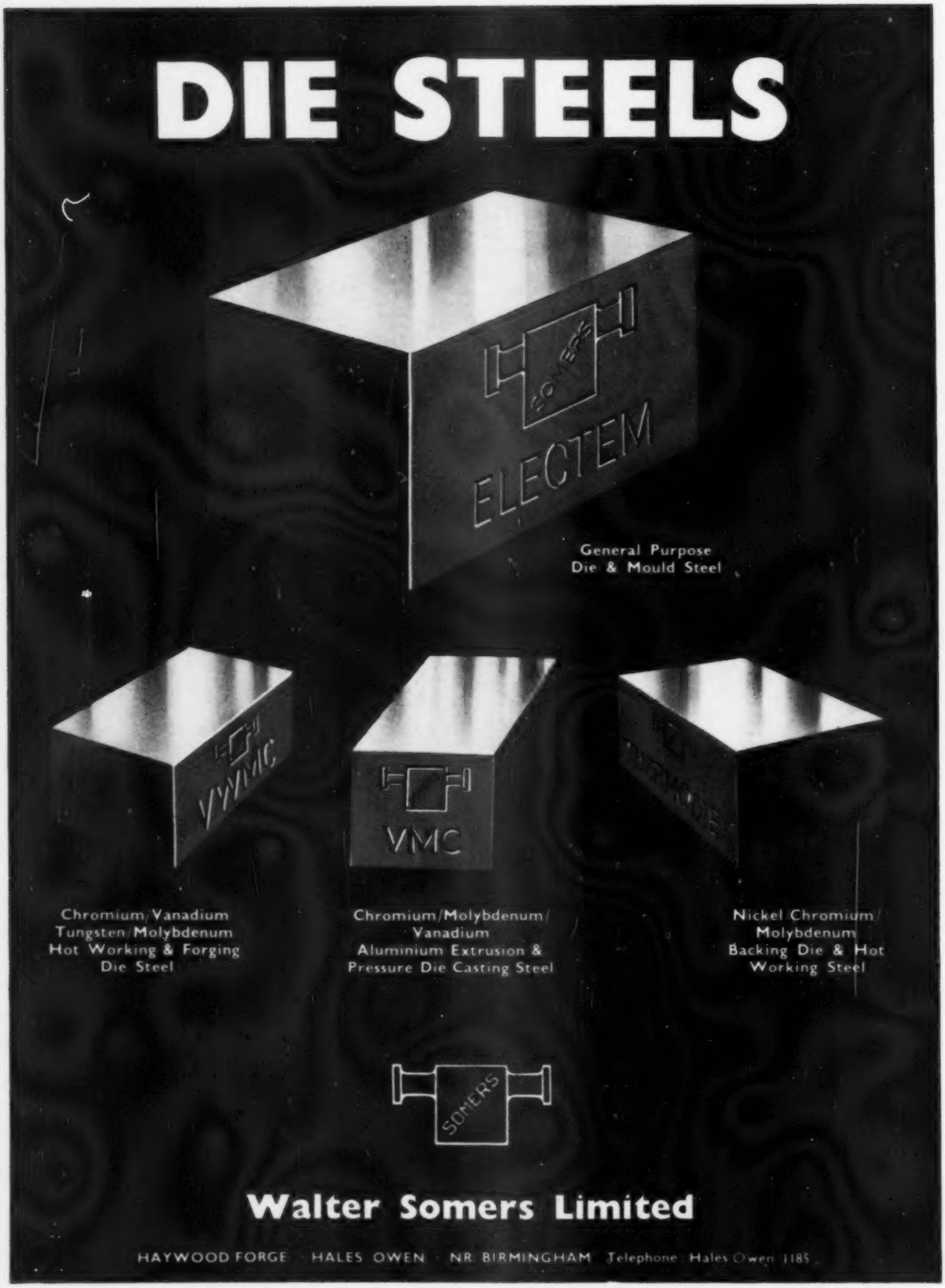
metal treatment

Vol. 28 : No. 190 JULY, 1961 Price 2/6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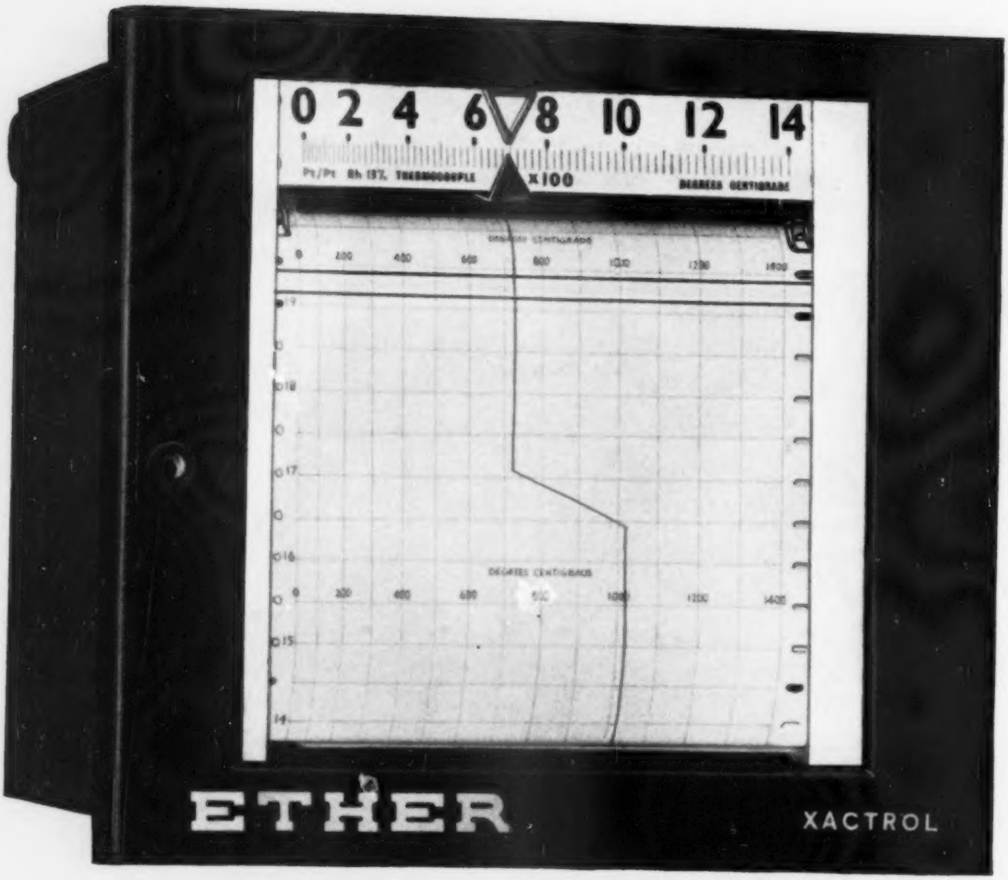

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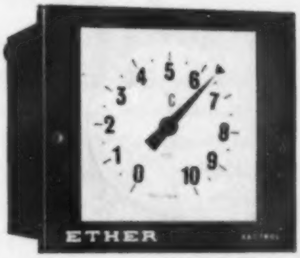

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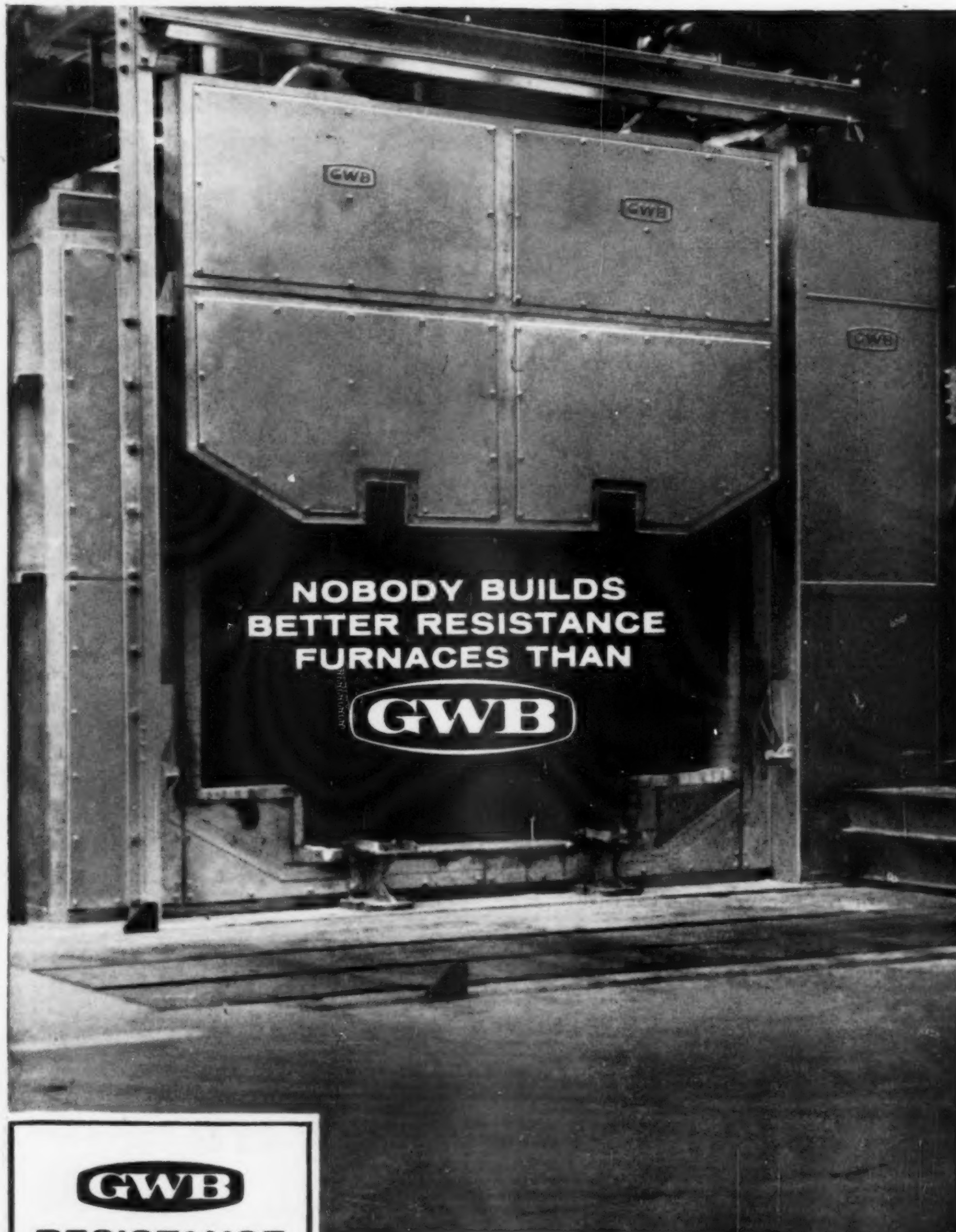

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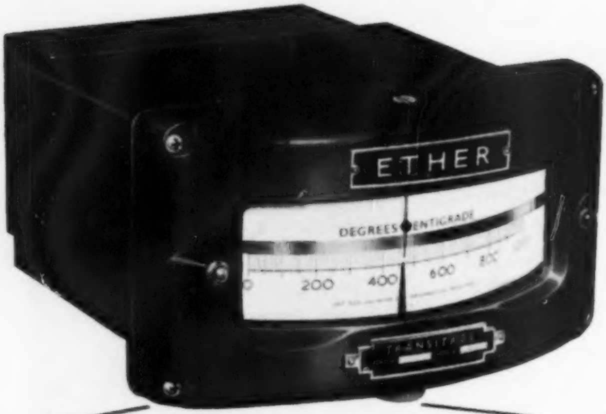

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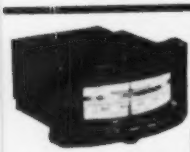

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Operating:
Solenoid valves.
Motorised valves.
Contactors. Relays.
Electric heaters.

Applications:
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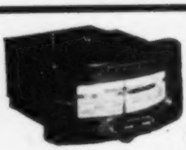
Muffle furnaces.
Hot-air ovens.
Drying kilns.
Crucible furnaces.
High-temperature alarms.
Extruding and moulding machines, etc., etc.



TYPE 991:
Anticipatory

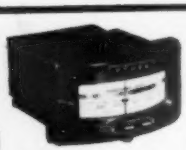
Operating:
Solenoid valves.
Motorised valves.
Contactors. Relays.
Electric Heaters.

Applications:
Extruding machines and moulding presses for plastics, rubber, etc.

Die-casting machines.

Furnaces for crystal growing.

Chemical processing.
Food packaging machinery, etc., etc.



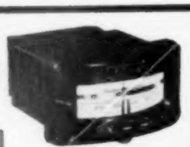
TYPE 992:
Proportioning (stepless)

Operating:
Saturable reactors.

Applications:
Electrically-heated equipment requiring extremely accurate temperatures, e.g. plastic extruders for high-quality production.

Electric furnaces employed on research.

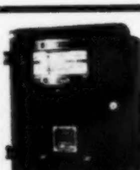
Electronic production, etc., etc.



TYPE 993:
Three-position (employing any combination of the preceding control systems).

Operating:
Solenoid valves.
Motorised valves.
Contactors. Relays.
Electric heaters.
Saturable reactors.

Applications:
For the independent control of sequential heating and cooling or for controlling a floating valve in:—
Salt-baths for heat-treatment of metals.
Vitreous-enamelling furnaces.
Muffle furnaces.
Crucible furnaces.
Extruding machines.
Moulding presses.
Die-casting machines, etc., etc.



TYPE 995:
Continuously-acting Proportional (with manual reset)

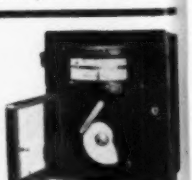
Operating:
Motorised proportioning valves.

Applications:
Gas-fired or oil-fired molten-metal vats.

Continuously-fed furnaces.

Lehrs.

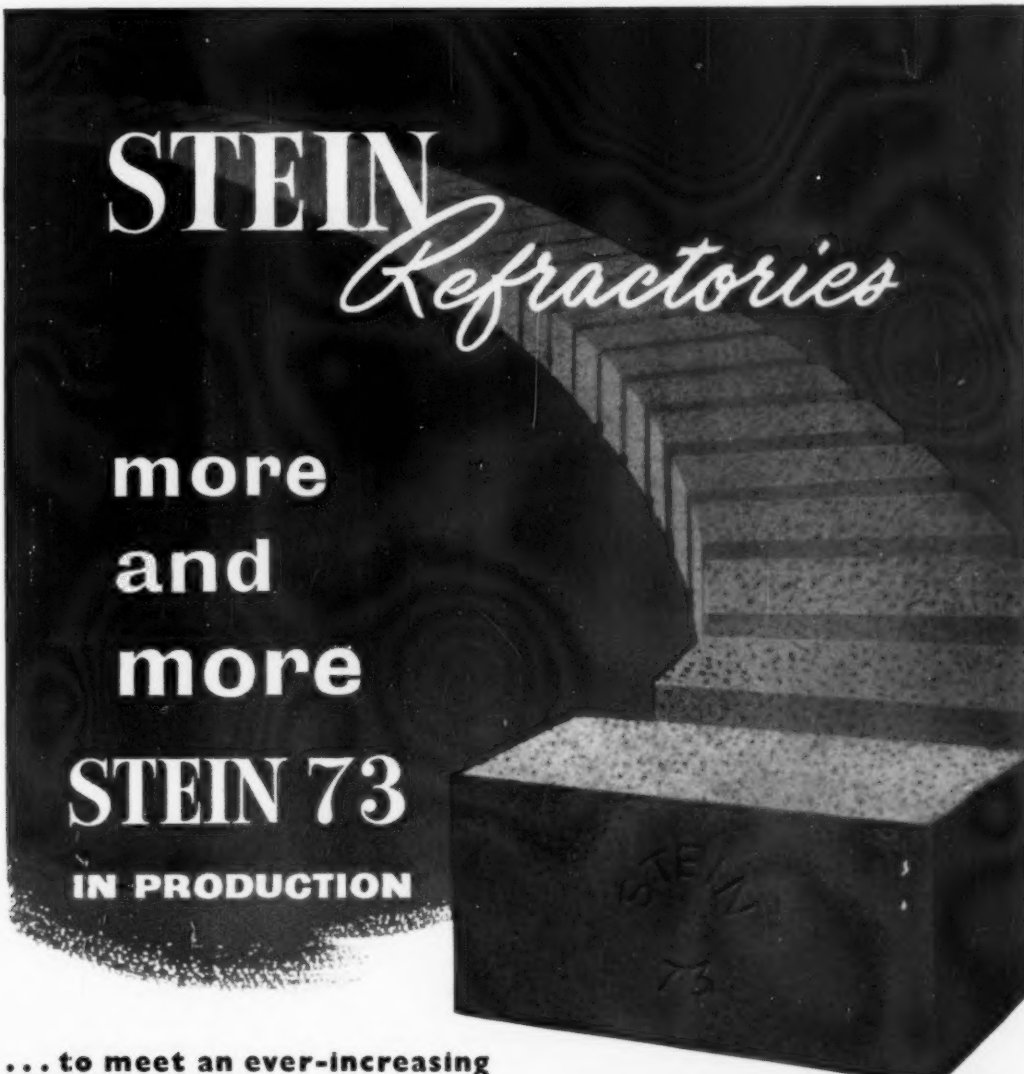
Drying ovens and kilns, etc., etc.



TYPE 994:
Time-Temperature (employing any one of the preceding control systems).

Operating:
Solenoid valves.
Motorised valves.
Motorised proportioning valves.
Contactors. Relays.
Electric heaters.
Saturable reactors.

Applications:
For controlling the rise and fall of temperature over a given period of time in:—
Pottery kilns.
Food processing.
Heat-treatment of metals, glass, plastics.
Research, etc., etc.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and Drop Forging

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Apprentice training

IN a recent editorial we stated that we had no wish to make ourselves ridiculous by putting forward our own unauthoritative opinions on educational problems. This is a charge, however, which can scarcely be made against the views of Sir Willis Jackson, F.R.S., who with wide experience in both research and education will again be returning to academic life this year as Professor of Electrical Engineering at Imperial College. In the 1961 Viscount Nuffield Paper, presented last month to the Institution of Production Engineers, Sir Willis made some timely criticisms of present technical educational policy. His remarks on the training of workers at the technician, craft and operative levels are paraphrased below.

National concern during recent years for our shortage of scientists and technologists has had the unfortunate consequence that the needs of other categories of industrial personnel have received much less attention than they deserve. Too little recognition has been given to the fact that the education and training of technicians, craftsmen and operatives is no less vital than that of scientists and technologists.

It has long been evident that the craft courses have afforded an inadequate foundation for the prospective technician, while, in so far as the National Certificate courses have provided an important route to exemption from the examination requirements of the professional institutions, they have been too academic for the majority of entrants. In consequence the failure rate in National Certificate courses has been extremely high, and the majority of those who have failed have withdrawn completely from further systematic study. What has been needed is a scheme of alternative courses, starting from school-leaving age, which would permit a process of selection *upwards* into National Certificate courses on *success*; not one of selection *downwards* into technician and craft courses on *failure*.

This is one of the objectives which the new pattern of courses for technicians, craftsmen and operatives, outlined in the recent Government White Paper ' Better Opportunities in Technical Education,' is intended to achieve. A particularly important feature of the proposals is the aim to establish a minimum of 330 hours of day-time college attendance as the *standard year* for all these courses.

The White Paper touches on four aspects of the contribution which it will be essential for industry to make. The first is close collaboration with the colleges and the examining bodies in the preparation of the syllabuses. The second is a more widespread willingness to release young people for participation in continued education during the day-time. The third is intimate co-operation with the staffs of the colleges in their selection of students for the alternative courses and the granting of appropriate recognition of their success in them; and the fourth, the provision of training schemes of adequate duration and standard.

It is all too evident that the educational plans within schools and technical colleges are not being matched by plans within much of industry. Unless steps are taken as a matter of urgency to correct this unbalance, what is being attempted in the educational sphere will come to only partial fruition.

Although Sir Willis was speaking with the engineering industry primarily in mind, it cannot be denied that, in spite of the excellent efforts of some firms, his remarks could equally well be taken to heart by our own industry.

National Association of Drop Forgers and Stampers

annual convention, 1961

WEATHER which could truthfully be described as 'gorgeous' assured the success of this year's NADFS annual convention from the moment of arrival. Held at the Grand Hotel, Eastbourne, June 21-25, the convention attendance numbered well over 150, including members, their wives and other guests. At the business sessions the brilliance of the speakers was more than adequate compensation for missing a few hours of sunshine outdoors, and lively interest was aroused by the well-chosen topics—all of current importance.

Mr. A. W. Reynolds, Birmingham Productivity Association, gave an admirably clear exposition of 'Work study' with particular reference to case histories drawn from the industry. Mr. H. Bewlay, Wm. Fowler, Bewlay & Co., brought to life the subject 'Developments in rating and valuation.' Mr. E. F. Yeomans, Industrial Administration Ltd., gave a most instructive talk on 'Industrial relations,' which was most interestingly complemented by the final contribution by Colonel Maurice Buckmaster, O.B.E., Industrial Administration Ltd. Colonel Buckmaster, in a witty and provocative talk, discussed the subject of 'Publicity and public relations.'

A reception by the president, Mr. S. Johnson, and Mrs. Johnson was held on Friday evening, June 23, prior to the convention banquet and dance, at which the Mayor and Mayoress of Eastbourne, Councillor and Mrs. J. B. Coventry, were the chief guests.

Attractions during the convention included coach trips to notable local spots, a visit to the Glyndebourne Opera for the lucky 50 who succeeded in the ballot, and the usual sporting events. Golf competitions were held on the Willingdon Golf Course and tennis at Devonshire Park.

Prize-giving took place on Saturday evening. The Gratwick Trophy for the golf competition went to Mr. L. Taylor, and the Alan Todd Trophies for the mixed double knock-out tennis tournament to Mrs. B. A. Butler and Mr. C. W. Robinson. The ladies' golf competition was shared by Mrs. J. F. Insch and Mrs. W. B. Bagshaw.

At the prize-giving ceremony, Mr. R. W. N. Danielsen, M.B.E., T.D., thanked the other members of the Convention Committee for their support, with a special word of praise to the Director and staff of the NADFS, whose hard work and excellent organization had contributed so much to making this year's convention an undoubted success.

Mr. and Mrs. H. Perry

Mr. and Mrs. J. F. Insch

Some groups at the drop forging convention

(Names read left to right)

1 *The President, Mr. S. Johnson, and Mrs. Johnson with the Mayor and Mayoress of Eastbourne, Councillor and Mrs. J. B. Coventry*

2 *Mr. W. Somers, Mrs. J. Dodd, Mrs. F. J. Hickman, Mrs. W. Somers, Mr. J. Dodd, Mrs. G. W. Richards, Mrs. A. C. Somers and Mr. A. C. Somers*

3 *The Director of the NADFS, Mr. A. L. S. Todd, C.B.E., J.P., with the Editor*

4 *The Director of the Drop Forging Research Association, Dr. P. H. R. Lane, being received by the President and his wife*

Russian forging journal

Abstracts from the Russian forging journal—'Kuznechno-Shtampovochnoe Proizvodstvo,' December, 1960, 2. This is the second year of this journal devoted specifically to forging. Short abstracts of the more important articles are given in METAL TREATMENT *each month.*

Experience in cold pressing of steel components. YU. F. FILIMONOV. Pp. 1–5.

Laboratory experiments are described which have led to the mass production of small tractor components by cold pressing.

Forces during the deformation of metal in box and oval passes. M. YA. BROVMAN and S. M. GENZELEV. Pp. 5–9.

Solution of plasticity theory problems for compression between two parallel and absolutely smooth plates has already been set out. The present article sets out calculation formulae for compression in box and oval passes within the limits

$$4 < \frac{l}{h} < 10$$

Flashless forging of compressor blade forgings in a combined action die. V. G. CHIZHOV. Pp. 9–11.

Application of the method to gas turbine rotor blades is described.

Some special features of the technique of plastic bending of bimetallic strip. I. A. CHECHETA. Pp. 11–13.

Methods of calculation of the spring angles of the base and cladding metals and allied problems are discussed.

Determination of the coefficient of external friction during hot stamping. N. A. KRAVCHENKO. Pp. 13–16.

A machine for determination of the external friction coefficient is described, and examples are given of its use to assess the quality of hot stamping lubricants on this basis.

Calculation of the permissible heating temperature of crank-drive press clutches for smooth operation. E. N. IZOTOV. Pp. 17–20.

A tube shingling press with synchronous movement of the rams. N. I. NAIGUZ and G. M. BERUL'. Pp. 21–25.

A full description is given of the 2,000-ton press capable of compressing the ends of 40 tubes per hour (of 80 to 408 mm. external diameter) before drawing.

Combustion of natural gas during non-oxidizing heating of steel in open flame furnaces. V. P. NIKIFOROV. Pp. 26–30.

The special feature of such furnaces is the two-stage system of combustion of the fuel, and the article describes research on the first of these stages with special reference to: (1) the relationship between the observed temperature in the furnace and the air supply conditions (air consumption coefficient); (2) the relationship between the air consumption coefficient and the composition of the furnace atmosphere; (3) the effect of the temperature and time factors on the intensity and trend of development of the reaction in the gaseous medium; and (4) the relationship between the necessary level of preheat of the primary air and the air consumption coefficient.

A combined manometer and hodometer. N. K. GOLUBYATNIKOV. Pp. 30–33.

The instrument, which is intended for research into operations carried out on a forging press under operational conditions, is fully described and, as an example, measurements of the main forging parameters have been tabulated for the forging of a 119·4-tonne ingot.

Stamping of stainless-steel base plates of large dimensions. V. V. RYBATSKII and N. I. STREL'NIKOVA. Pp. 36–38.

Base plates 12-mm. thick and 3,024 mm. in diameter are stamped on a 2,500-ton press in two halves and welded together.

An 800-ton hydraulic forging press of the firm of 'Fielding.' P. N. FROLOV and R. G. DAVYDOVA. Pp. 38–44.

Improving the design of a model K864 hot stamping press. S. L. ROITBURD, V. I. KHRAMCHENKO, A. I. SOROKIN, I. N. YAKUBENOK and B. F. MIKHAILICHENKO. Pp. 44–46.

Improvements are outlined in the light of production experience on this 1,600-ton crank-drive, hot stamping press, manufactured at the Chelyabinsk Works. The stroke length is 300 mm., and the press works at 75 strokes/min. Improvements relate mainly to the braking system for the strip and the ejector mechanism.

Observations concerning the structure of scale, and the mechanism of formation during the heating of steel

STEN MODIN and ERIK THOLANDER

An investigation has been carried out of the conditions of the formation of scale and its properties during heating in an electric furnace in an atmosphere of air and in an oil-fired furnace. A report is given of observations and conclusions in connection with a number of preliminary experiments, the majority of which were conducted in an atmosphere of air in an electric furnace. The experimental material was made up of three unalloyed steels and electrolytic iron. One steel was a 0·1% *C rimming steel, and two were killed with silicon and contained* 0·2 *and* 0·7% *C respectively. The temperature was varied between* 1,000 *and* 1,300°*C. This English version is a translation from the original Swedish which appeared in 'Jernkontorets Annaler,' November,* 1960. *Mr. Modin is with the Swedish Institute for Metal Research (Metallografiska Institutet), and Mr. Tholander is head of the Forging Practice Department of the Sveriges Mekanförbund*

THE OXIDATION OF STEEL during heating entails losses, which are partly direct losses of material, and partly indirect costs caused by poor external quality, wear on tools, various measures for removal of scale, etc.

The last-named costs are of special importance so far as drop forging is concerned, where the purchasers' demands for high quality, accurate dimensions and low production costs continually increase. Despite a comprehensive literature, which handles the problem of oxidation in various ways, and has been deservedly compiled in book form by Kubaschewski and Hopkins[1] in England and by Hauffe[2] in Germany, it has hitherto been impossible to find satisfactory answers to sundry questions relating to the behaviour of steel during heating for hot working, either from the authors mentioned or in investigations published later.

Some examples of such unanswered questions are the following: Why is scale sometimes easy to remove, while in other instances it holds hard and fast to the surface of the steel? Why do we obtain scale with various appearances and adhesive properties as a result of heating in an electric furnace and in an oil-fired furnace? Why does scale sometimes reveal a blistery appearance? Is there some connection between scale formation and surface decarburization? The list of questions can become quite long, if continued.

In an attempt to acquire greater knowledge of the problem of scale and/or the factors which influence the process and determine the properties of scale, a series of experiments on the heating of steel of various types and under various external conditions have been put in hand in the forging department of Sveriges Mekanförbund. At the Metallografiska Institutet a microscope investigation of the structure has been carried out on the heated experimental material. Up to now, the experiments have had only the nature of preliminary research, but, since they have already led to some partially new observations and conclusions, which can likewise acquire importance for research into oxidation being carried out in other quarters, it seemed suitable to publish the following account. Meanwhile the investigation continues with economic support from the State Technical Research Council, so there should be occasion to return in the future with more comprehensive reports.

Experiment procedure

Furnace plant For experiments carried out so far, use has been made of the furnaces and instruments, which form part of the experimental forging shop in the forging laboratory in Eskilstuna, and which are intended for heating billet material for a 100-kpm. air hammer and a 500-kpm. drop hammer. Of the two furnaces employed (each with a hearth area of about 0·2 m.^{2}), one is oil-fired and the other electric with a resistance element capable of withstanding high temperature. The majority of the experiments so far conducted have been carried out in the electric furnace.

The electric furnace has a working load of 24 kW., and is equipped with nine silicon-carbide ' Crusilite ' elements (Morgan Crucible Co. Ltd.) which are mounted horizontally under the roof in the upper part of the furnace chamber. Control is carried out automatically by means of an Osmund photo-electric cell controller and a signal from a platinum-platino-rhodium thermocouple placed in the rear wall of the furnace chamber.

The oil-fired furnace is a muffle furnace from Fabriksaktiebolaget Osmund in Uppsala, and is equipped with a self-regulating burner for a maximum oil consumption of about 15 kg./h. The flue gas preheats the air for combustion. The furnace is automatically controlled by means of an Osmund system control motor, which is governed by an Osmund photo-electric cell controller by signal from a platinum-platino-rhodium thermocouple placed in the furnace roof.

The temperature regulation gives rise in both furnaces to a fluctuation in temperature of the furnace chamber between an upper and a lower limit value, the upper limit being the nominal temperature for which the setting has been made. The real maximum temperature in the range of 1,100–1,300°C. during the experiment in the electric furnace should have been within ±20°C. from the nominal. For example, at 1,200°C. as the nominal temperature a difference between the upper and lower limit of 35–40°C. was obtained on reading the temperature of the back wall of the furnace with an optical pyrometer, and about the same value from a thermocouple placed on the bottom of the furnace. At 1,300°C. a somewhat smaller, and at 1,100°C. a somewhat larger, difference was obtained. The fluctuation occurred through the fact that control takes place between full load and zero.

The scale formed during the experiment, therefore, was produced within a temperature range having the nominal temperature as the highest value and an accuracy of about ±20°C. This was considered to be satisfactory for these preliminary experiments, and should, moreover, correspond well to the heating conditions, which occur in practice especially in smaller furnaces with similar control systems as here.

No gas analyses were made in relation to the furnace atmosphere. In the oil furnace, test-pieces were heated at two different points, *i.e.* some as near to the burner as possible, and some as far from it as possible. The oxygen content of the gas was taken to be higher close to the burner than farther away, where pre-combustion must have brought about a reduction. The height of the burner above the furnace bottom was about 16 cm. In the electric furnace, heating took place in an atmosphere of pure air.

Material The materials used for the pilot experiments described, were high-purity electrolytic iron, a rimming steel and two carbon steels containing respectively 0·2 and 0·7% C. The analyses may be seen from table 1.

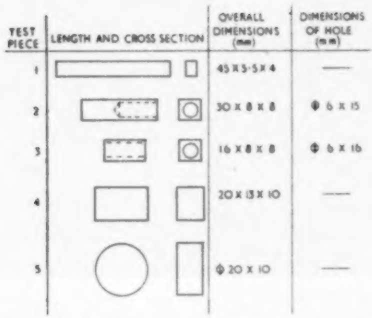
Experimental method Three sorts of series of experiments were carried out with the aim of studying the following problems: 1. Macro- and micro-structure of the scale and the thickness of the layer; 2. Behaviour of the scale during hot bending; 3. Effect of the heat liberated by oxidation on the scale formation temperature.

The first group of experiments, which makes up the greater part, was carried out in such a way that the test-piece was placed at a fixed point on the furnace bottom when the furnace was already heated up to the experimental temperature. The time was taken from the charging of the specimen, so that heating times indicated include both the time taken to heat up the specimen and the holding time at the experimental temperature. On account of the varying dimensions and volumes of the different types of test-piece, the heating-up time

TABLE 1 *Analyses of the experimental material*

Mark	Type of steel	Composition, %					
		C	Si	Mn	P	S	Cu
E	Electrolytic iron*	—	—	—	—	—	—
P	Rimming carbon steel	0·09	trace	0·53	0·008	0·021	0·13
U	Medium hard, carbon steel	0·72	0·32	0·45	0·032	0·019	—
V	Mild, killed steel	0·22	0·24	0·50	0·032	0·029	—

*Only slight impurities: Co 0·005%, Zn 0·005%, remaining substances <0·001%



1 *Test-pieces for the study of scale during the preliminary heating experiments reported in the paper*

varied for the different series of experiments. The heating times given, therefore, were only approximately measured according to the duration of oxidation.

The times employed varied between 2 and 12 min. It was shown that, with the small test-pieces, scale of sufficient thickness is obtained after only 3–6 min., so that the majority of tests were carried out with these experimental times.

Every test-piece, after removal from the furnace, was rapidly transferred to a steel-plate vessel, which was streamed through with nitrogen gas of commercial quality. Cooling took place rapidly without further oxidation worthy of mention.

The dimensions and appearance of the test-pieces may be seen in fig. 1. The long test-piece, type 1, was exclusively used for bend tests. Type 2 is the type first used for the purpose of studying the structure of the scale. The hole bored into the test-piece to half its length was introduced so that the oxide formed on the wall of the hole should be better protected against flaking off during transport between the forging laboratory and the Metallographic Institute. As will be shown, however, in certain instances no oxide was formed in the hole. Type 3 was made shorter than type 2 to facilitate the preparation of the specimen for microscopic examination, and the hole was made to pass right through the test-piece in order to give the furnace atmosphere better access. Type 4 was only used during the oxidation of electrolytic iron, which was delivered in pieces with a cross-section of 13 × 10 mm. Type 5 was only employed during one single experiment to measure the oxidation temperature of the exterior with the aim of obtaining test-pieces of about the same volume during a parallel experiment with electrolytic iron.

In all instances the experimental temperature was controlled with the control equipment described. During some series of experiments check measurements were made with thermocouple and potentiometer or with optical pyrometer, during which good agreement was obtained with the control instrument.

During the experiment to study scale structure, test-pieces of types 2, 3 and 4 were used. After cooling, first of all a visual examination was made, and then the test-pieces were sent to the Metallographic Institute. S. Modin describes the method used for this work and the result of the investigation of the structure in a separate report.[8]

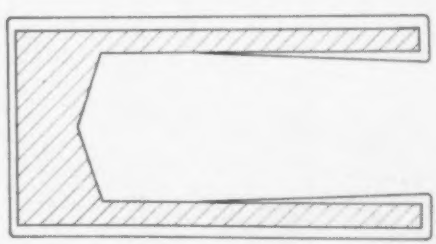
For the hot-bending tests mentioned above a number of test-pieces of type 1 were clamped by one end vertically in a fixture which was then placed in the furnace. When the test-piece approached the furnace temperature, and had been held at this temperature for the determined time, the free ends of the test-piece were subjected to loading, until bending occurred. Bending was carried out for different lengths of time, but it was shown that no advantage was gained from bending to greater angles than 20–30° from the initial position, as the scale loosened and fell off at this magnitude of bending angle.

For the study of the increase in surface temperature during the course of oxidation, test-pieces of types 4 and 5 were heated in the electric furnace. The temperature was determined with an optical pyrometer, which was read off every 10 sec., alternately taking the temperature against the test-piece and the furnace wall. In order to make possible rapid reading, these experiments were carried out with two observers, one of whom carried out the insertion of the hot junction while the other read off the deflection of the indicator.

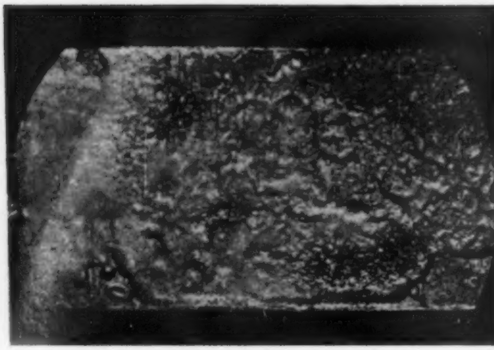
Macro-formation of scale

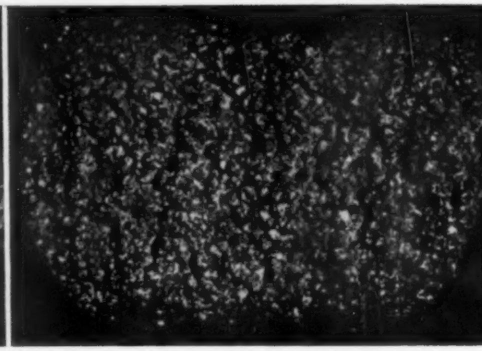
The properties which are to be noted in this connection are: scale thickness; external colour and reflective power; evenness of scale surface; occurrence of blisters or bubbles; and tendency to cracking or flaking.

Thickness of the scale is known to be primarily dependent on the heating temperature and holding

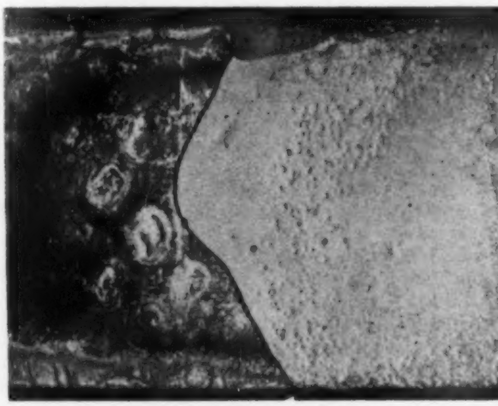


2 *Diagram showing the distribution of scale on test-pieces with drilled-out holes. Sometimes no scale is formed in the bottom of the hole*

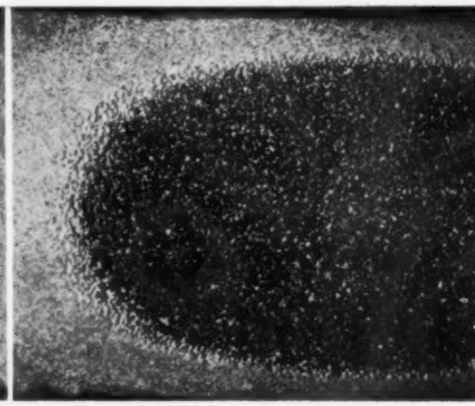




3 *Examples of scale formed on 0·7% C steel in an oil-fired furnace after heating for 3 min. at 1,100°C.* **a** *Test-piece placed in the furnace on the side of the burner.* **b** *Test-piece placed in the furnace on the side opposite the burner*



4 *Scale on electrolytic iron after heating for 6 min. at 1,100°C. in an electric furnace in an air atmosphere. The smooth oxide surface on the left is characteristic of this material, and also the tendency of the scale to flake off*



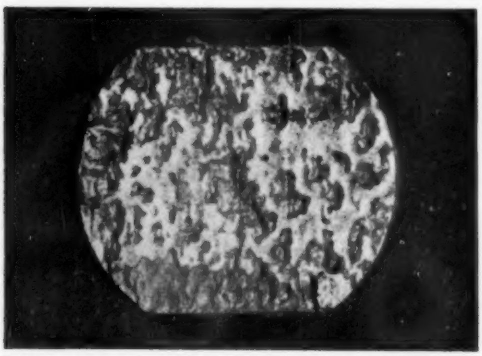
5 *Scale on electrolytic iron which was heated at 1,200°C. for 3 min. in an electric furnace in an air atmosphere. The large, dark area, which lies in the centre of the surface of the specimen and covers 60–70% of it, had a higher temperature during heating than the surrounding material. Its surface is not smooth, but covered with small octahedral crystals*

6a *Scale on rimming steel heated for 6 min. at 1,000°C. in an electric furnace in an air atmosphere. The scale contains blisters and flakes off very easily. Between the blisters can be detected marks from machining*

6b *Scale on rimming steel heated at 1,200°C. for 3 min. in an electric furnace in an air atmosphere. The scale between the blisters shows traces of machining on the surface of the steel*

7b *Scale on 0·2% C killed carbon steel, heated for 3 min. at 1,200°C. in an electric furnace in an air atmosphere. Blisters occur for the most part along the edges of the test-piece*

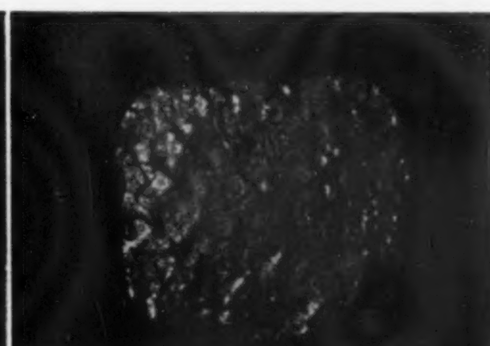
7c *Scale on 0·2% C killed carbon steel, heated for 6 min. at 1,200°C. in an electric furnace in an air atmosphere*



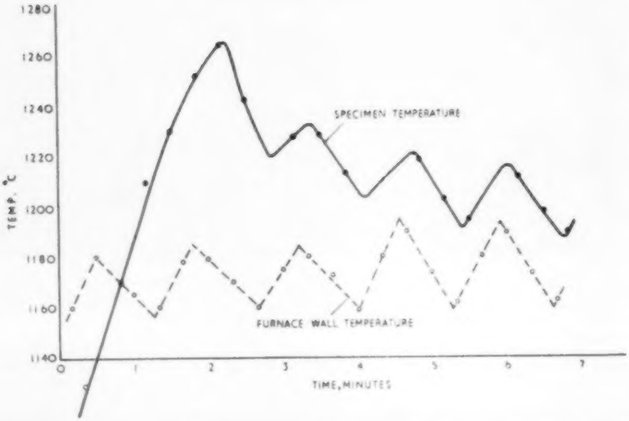
7a *Scale on 0·2% C killed carbon steel, heated for 6 min. at 1,000°C. in an electric furnace with an air atmosphere. The dark areas are blisters, which have wrinkled and partly flaked off*

8a *Scale on medium-hard 0·7% C steel, heated for 6 min. at 1,000°C. in an electric furnace in an air atmosphere*

8b *Scale on medium-hard 0·7% C steel, heated for 6 min. at 1,100°C. in an electric furnace in an air atmosphere. The blisters flaked off extensively*



8c *Scale on medium-hard 0·7% C steel, heated for 6 min. at 1,200°C. in an electric furnace in an air atmosphere*



9a *Temperature curves recorded with a Pyropto optical pyrometer placed against the specimens and against the wall of the furnace during the heating of electrolytic iron in an electric furnace in an air atmosphere. The furnace temperature was automatically regulated by switching on and off the total power. The nominal furnace temperature was 1,200°C. The maximum temperature of the surface of a specimen lies about 80°C. above the furnace temperature*

time at this temperature. Measurements made during the microscope investigation[8] confirm this, although there were certain difficulties in making exact determinations in instances where the scale had a strong tendency to flake. The experiments made with the drilled test-pieces show, nevertheless, that scale thickness can be reduced considerably even in a strongly oxidizing furnace atmosphere, merely by restricting the delivery of oxygen to the surface of the steel. In the hole of the drilled test-pieces the oxide layer was, in the majority of instances, very thin, and on specimens heated in the oil-fired furnace was, in some cases, completely non-existent. Scale formation on the drilled test-piece can, in principle, be illustrated as in fig. 2.

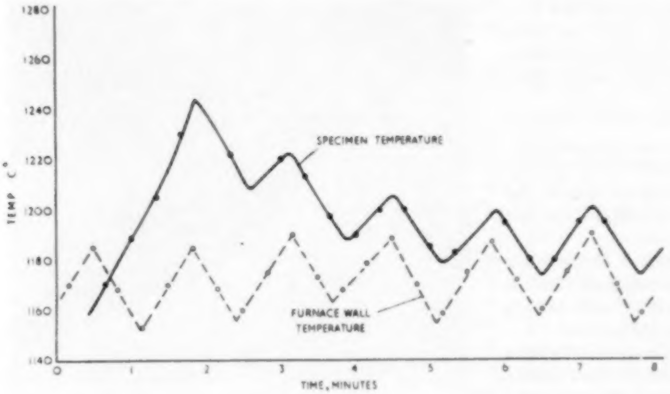
The scale formed in the oil-heated furnace displayed such changing characteristics that within the framework of these preliminary experiments it has proved impossible to pronounce closely on the connection between the causes, until these have been studied during the continued investigation. A common property of various test-pieces was, however, that the scale adhered firmly after cooling, showing little tendency to flake. In the majority of experiments the outside of the test-piece had a rather dull appearance on account of numerous small crystals of octahedral form, but in some instances specimens heated on the burner side of the furnace were obtained with gleaming bright surfaces. Blisters and pores in some instances gave the scale a granular appearance. Examples of scale formed in the oil-fired furnace are shown in figs. 3*a* and *b*.

The scale formed in the air atmosphere in the electric furnace showed a completely different character to that obtained in the oil-fired furnace. Without exception it had a strong tendency to flake during cooling, and on the carbon steel there were inflated bubbles, most frequently to a considerable extent. Here, there exist somewhat more comprehensive data, as is apparent from the following:

Electrolytic iron E Scale was formed at all temperatures with a smooth surface without any formation of blisters at all. The scale flaked easily. See fig. 4. With a short holding time and a furnace temperature of 1,200 and 1,300°C., on the surface of every test-piece a lustreless, centrally placed spot with crystalline surface was formed having the appearance seen in fig. 5. The spots coincided in position and extent with those parts of the surface which showed that they had acquired a higher temperature than the furnace temperature during heating, on account of the evolution of heat occurring during oxidation. With longer holding times than 3 min. such spots were not obtained, which could indicate that uneven features in the structure of the scale caused by the formation temperature are evened out, when the temperature on the surface of the test-piece is evened out.

Steel P (0·1% *C, rimming steel*) On this material without exception the scale shows a high degree of blister formation with a strong tendency to flake during and after cooling. The surface is smooth and grey in colour. The blisters are of two sorts, with a more domed, brighter type, and a less domed, but more brittle, type. See figs. 6*a* and *b*. The light-coloured blisters seem to be inflated with gas under pressure, which stretched the scale in the wall of the blister. The dark, low blisters reflect in relief the traces of machining on the surface of the steel. No greater effect seems to have arisen from the heating temperature, except that the light-coloured, more arched blisters increased somewhat in size at higher temperature. Under the blisters which flaked, the surface of the steel is covered by a dark-coloured, thin film of sparkling, crystalline character.

Steel V (*killed*, 0·2% *C, steel*) At all temperatures



9b *Temperature curves recorded in the same way as in* **9a,** *but with test-pieces of killed* 0·2% *C steel. The maximum temperature of the specimen lies about* 60°C. *above the furnace temperature*

the scale is strongly subject to blisters, but their size increases with rising temperature. During and after cooling, the blisters are brittle and flake easily. Between the blisters the surface of the scale is moderately even and smooth, and seems to adhere well to the surface of the steel. See figs. 7*a–c*.

Steel U (0·7% *C, killed steel*) This material likewise oxidizes with formation of blisters, as may be seen from figs. 8*a–c*, but the size of the blisters tends to decrease with increasing temperature. On test-pieces heated at 1,000 and 1,100°C. the brittleness and the tendency to flake after cooling is about the same as with steel V, but on test-pieces heated at 1,200°C. a scale was produced which adhered more firmly.

Observations during heating in air

When a cold test-piece is charged into a hot furnace, a certain time elapses before the test-piece takes on the furnace temperature. With the test-pieces and temperatures employed in this instance, the heating-up time varied between 1 and 2 min. In connection with the heating up of test-pieces in the electric furnace with an atmosphere of air, two special phenomena were observed, both having a connection with the sequence of scale formation. The first observation relates to blisters. With the carbon steel it was shown, in fact, that such blisters come up on the surface of the test-piece at a relatively early stage, *i.e.* when the temperature should be between 800 and 900°C.

The other observation relates to the temperature of the test-piece. As may be seen from figs. 9*a* and *b*, the surface temperature of the test-piece continues to rise to a quite considerable extent above the furnace temperature, which can scarcely be explained otherwise than that an excess of heat energy is developed during oxidation. The excess temperature was not the same over the whole surface of the test-piece, but was lower at its edges. Thus on a rectangular surface of a test-piece an oval patch was formed of greater luminosity than outside the patch. During measurement of the temperature with the optical pyrometer, the hot junction was directed towards the hotter part of the test-piece. On electrolytic iron a difference in temperature of up to about 80°C. was measured, and on rimming steel of up to about 60°C. That the edges of the test-piece, and the surface nearest to them, remain colder can be accounted for by the fact that the heat radiation into the surrounding atmosphere remains greater in these areas, as reckoned by the unit volume of steel under the surface. Earlier excess temperatures have been indicated by H. Baumann[7] during the oxidation of iron in oxygen.

Conclusions concerning the sequence of the scale formation in air

When the results of the microscope investigation of Modin[8] are considered together with the observations made during the heating experiment and the visual examination of the experimental material, the following facts can be noted:

1. The innermost layer in the scale consisting of FeO is supersaturated in oxygen.
2. Blisters arise on carbon-containing material even during the heating-up process, when the scale must still be very thin, and before its surface approaches the furnace temperature.
3. In addition to blisters the scale also contains pores, which likewise occur in carbon-free electrolytic iron.
4. Surface decarburization under the oxide film shows that carbon has left the surface of the steel. This must have occurred through the reaction with oxygen to form CO.
5. The thickness of the scale decreases with increasing carbon content.

6. A molten phase, which *inter alia* occurs as a thin film between the steel and the scale, has been discovered on steel killed with silicon and manganese, within the whole temperature range from 1,000–1,300°C.

7. The molten phase does not occur on electrolytic iron and rimming steel not containing silicon.

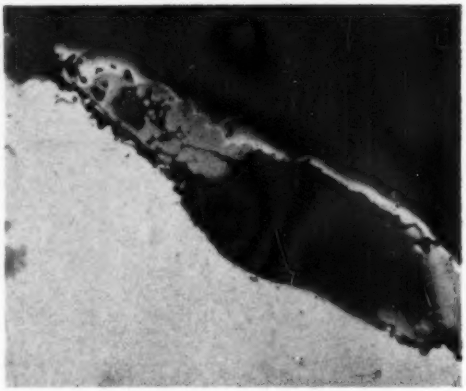
8. An excess temperature of 60–80°C. above the furnace temperature can occur in the surface of the scale as a result of the heat developed by the reaction during oxidation.

If, furthermore, we restrict ourselves to the scale formation which occurs during oxidation of steel in air, on the basis of what has been set out above, the following conclusions can now be drawn.

When steel is heated in contact with free oxygen a film of scale is formed which contains iron oxides in three different stages of oxidation, of which the innermost and strongest is FeO. Iron diffuses outwards through the oxide film and oxygen diffuses inwards. The carbon which is in the oxidation zone of the steel reacts successively with either iron oxide already formed or oxygen transported inwards, to form gaseous carbon monoxide. Where the carbon content is high, more oxygen is consumed in the formation of CO, so that the adhesive oxide film becomes thinner on hard steel than on mild steel under otherwise equal heating conditions. Mn and Si react likewise to form their oxides or manganese silicate. What happens with contaminations of the steel with P and S, etc., is left for the moment open. The carbon monoxide cannot diffuse, or has great difficulty in diffusing, out through the oxide film. It is, therefore, accumulated under rising pressure in the pores in the film and in the cleavage openings, which are formed between the scale and the surface of the steel as a result of the increase in the volume of the film and the consequent slip towards, and over, the edges of the piece of steel.

The temperature of the oxide film increases continuously with time, and the FeO film, which has the lowest fusion point of the iron oxides, should soften. When the pressure in the entrapped CO gas locally exceeds the load limit of the scale, which corresponds to its actual yield-strength value, blisters are formed in the scale.

When the skin of oxide over a blister loses contact with the surface of the steel, it is cut off from the supply of iron atoms. The growth in thickness stops, but the degree of oxidation increases, so that the FeO film disappears, and only Fe_3O_4 and Fe_2O_3 remain (fig. 10). At the same time the hardness of the scale over the blister can be taken to increase, since the fusion points of the higher oxides are higher than the fusion point of FeO. Strength values for the oxide film are still, unfortunately, not available but, since scale also wears uniformly on hard steel, we should be justified in counting on



10 *Section through the scale on medium-hard 0·7% C steel, heated for 6 min. at 1,000°C. in an electric furnace with an air atmosphere*

higher values. There is, therefore, reason to assume that the cover over the blisters in the oxide film successively hardens, and that, therefore, the gas pressure in the blisters can rise proportionately, as oxidation proceeds, and more CO gas is formed. With a large quantity of gas or a rapid rise in pressure, *e.g.* as a result of a high carbon content in the steel, very rapid oxidation or a high rate of rise in temperature, it should nevertheless also be possible for the phenomenon to occur, the gas pressure causing the blisters to burst. If, then, the scale is still formed by FeO and continues to be relatively soft, the top of the blister should sink into itself and become wrinkled like an empty balloon. But if the puncturing takes place after higher and harder oxides are formed in the top of the blister, this may be expected to remain with some sort of opening to show what has occurred. In both instances oxygen-containing furnace atmospheres should once again be able to penetrate to the surface of the steel, and thereby continue the oxidation under the old blister.

The oxidation products of silicon and manganese do not seem to be able to diffuse outwards but remain in contact with the steel. According to Hauffe[2] (p. 259), it has been stated that there is silicon enrichment in the boundary layer between the steel and the scale. When the temperature exceeds the fusion point of the component with the lowest fusion point, a film of molten material is formed in the boundary zone. This seems to take place at relatively low temperatures when both Si and Mn are present. That the molten phase is observed in test-pieces which are oxidized at as low a furnace temperature as 1,000°C. is not, however, any certain proof that the real temperature within

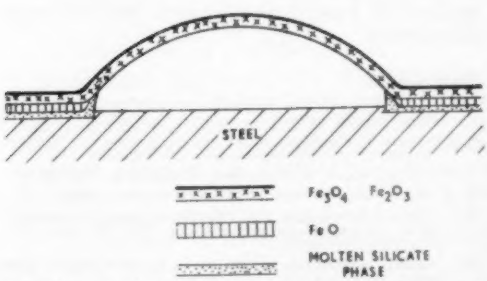
the scale was equally low, since the heat liberated during oxidation can, in addition, give an excess temperature which lies considerably higher.

The occurrence of a molten phase can be assumed to have a strong influence on the kinetics of the continued oxidation. In the molten phase, in fact, the diffusion velocity increases many times, to which attention has been drawn by many authors in relation to the so-called catastrophic oxidation of steels alloyed with Mo and V. Formerly, however, none except Modin seems to have pointed out a molten silicon phase in the scale on unalloyed steel at such low heating temperatures as during the present investigation.

During the formation of blisters in the manner described above, the molten phase, on account of its surface tension, becomes accumulated in the corners formed between the scale and the steel at the foot of each blister, and also subsequently becomes enriched under those parts of the scale which lie between the blisters. This is diagrammatically illustrated in fig. 11. The molten phase thus acts as a paste between the steel and the scale, and, at the same time, its presence increases the diffusion velocity of the iron atoms passing from the steel to the oxide film. The surface of the steel is strongly eroded between the blisters. If the blisters are punctured, conditions are created not only for continued oxidation beneath them, but likewise for continued erosion through renewed formation of the liquid silicon phase.

The interpretation given here of the formation of blisters and the part played by the molten phase in this process, seem to be in good agreement with the data given in the literature concerning blistery scale, which have been compiled by Kubaschewski and Hopkins[1] (page 64).

The molten silicon phase should certainly have great importance for the adhesion of the scale to the surface of the steel. If the surface of the steel is strongly eroded, there is also an increase in the contact surface between the steel and the scale, while at the same time the scale becomes more securely



11 *Diagram of the build-up of scale with blisters and liquid-silicate phase*

anchored, and possible slippage is obstructed. A new light will, therefore, probably be thrown on the problem of scale removal if the interpretation presented above of the oxidation sequence is confirmed and the contributory factors' varying degrees of influence are clarified in greater detail.

Plasticity and adhesion properties of the scale

In general, there is reason to regard scale on steel as being hard and brittle, not only at room temperature but also at the actual temperatures for hot working. A well-known exception happens by the heating to 'welding temperature,' when the temperature should in every instance exceed the fusion temperature of FeO, which is 1,370°C. The range of temperatures normal today during heating for both forging and rolling can be considered to be 1,100–1,250°C., at which none of the oxides of iron can occur in liquid form. The bending tests described above also gave evidence that the scale worked in a brittle manner and loosened after little bending when the temperature was about 1,200°C.

There is, however, one indication that scale, or certain of its components, must possess a certain plasticity, *i.e.* the occurrence of blisters. These must indeed have undergone a partial plastic deformation of the scale over each blister, in the event that they were caused by gases which expanded. This is, at all events, natural also, since in every instance the fusion point of FeO is so close to the temperatures which were established during this investigation as prevailing in the outer surface of the steel during oxidation, that we must reckon on the possibility that the FeO phase softens and approaches a more or less plastic state. That, despite this, the scale can become brittle, can be due to the fact that the outer layers of higher oxides are brittle, and that it is these which break away under mechanical stresses on the scale. The problem of the plasticity of scale is one of the partial problems entering into this investigation which have not yet been satisfactorily explained, but which has great practical importance, where the question of the removal of scale from steel before forging is concerned. Further attention will, therefore, be devoted to it.

In order to attempt to judge quantitatively the reasonableness of the statement that blister formation in scale is based on a combined reaction between the pressure in a gaseous oxide phase and the adhesive properties of the tenacious oxide film, the following rough calculation will be made. At the same time, however, it must be premised that the calculation suffers from an essential weakness, in that it presumes a certain static balance of the components, while the real process is dynamic to a high degree.

We assume, first, that the actual material is a 0·1% C carbon steel, that the temperature is 900°C., and that the thickness of the scale formed is 0·05 mm. This corresponds to a layer of steel of about 0·025 mm. thickness. Per cm.^{2} of the surface of the steel a volume of $2 \cdot 5 \times 10^{-3}$ cm.^{3} is thereby oxidized with a weight of 0·0195 g. In this thin flake of steel there is $1 \cdot 95 \times 10^{-5}$ g. carbon, which is oxidized to CO with a volume at 0°C. and 760 mm. Hg of $3 \cdot 65 \times 10^{-2}$ cm.^{3} At 900°C. and unchanged pressure, this quantity of gas should occupy a volume of about 157 mm.^{3}

Let us now assume that the quantity of gas from 1 cm.^{2} of the surface of the steel is collected in a single cavity, and that it throws up a blister with a height of about 1 mm. and a diameter of about 8 mm., *i.e.* the blister covers about 50% of the surface of the steel.

The volume in this blister remains of the order of size of 40 mm.^{3} In order that the quantity of gas calculated above of 157 mm.^{3} at 900°C. shall find room in the blister, an excess pressure is required within it of about 3 atm. This should give a tension at the base of the 0·05-mm.-thick wall of the blister, which would be of the order of 1·2 kp./mm.^{2}

If the temperature is changed upwards or downwards, the gas pressure is changed in a corresponding manner by 8–10% per 100°C., and thereby the tension. This is also influenced by the volume of the blister and its wall thickness, the quantity of gas formed, etc.

The question whether the example of calculation given above yields reasonable values for the pressure of the gaseous phase and the tension on the wall of the blister, will be answered during the continued investigation.

Summary

An investigation has been carried out of the conditions of the formation of scale and its properties during heating in an electric furnace in an atmosphere of air and in an oil-fired furnace. In this paper a report is given of observations and conclusions in connection with a number of preliminary experiments, the majority of which were conducted in an atmosphere of air in an electric furnace. The experimental material was made up of three unalloyed steels and electrolytic iron. One steel was a 0·1% C, rimming steel, and two were killed with silicon and contained 0·2 and 0·7% C respectively. The temperature was varied between 1,000 and 1,300°C.

A report has been given on the microstructure of the scale in a separate paper by S. Modin. The macrostructure and appearance of the surface after cooling betrays a considerable difference between the electrolytic iron on the one hand and the three carbon steels on the other, when they are heated in air. The former oxidizes with a surface which is, for the most part, even and smooth, into compact platelets of oxide which flake off readily. On the carbon steel, more or less well-developed blisters form in the oxide layer. The blisters are brittle and flake off easily. In bore holes oxide layers of rapidly diminishing thickness are produced on account of the fact that the gas circulation and thereby the supply of oxygen is diminished or completely cut off. Scale on test material, which is heated in an oil-fired furnace, partly has a completely varied appearance, sometimes with a sparkling, crystalline surface, and sometimes with shining, almost smooth surface. The connection between the causes has not yet been clarified.

During heating in air it was observed that oxidation gives rise to an excess temperature on the surface of the steel, which was measured with an optical pyrometer at 60–80°C. above the furnace temperature, and that blisters were formed on test-pieces of carbon steel even during heating up, and when the temperature was estimated at 800–900°C.

In a hypothesis concerning the sequence of the formation of scale, it is assumed that blister formation is dependent on the fact that the gas pressure from CO gas, which forms the product of the reaction with the carbon liberated during the oxidation of the steel, gives rise to a plastic deformation of the layer of FeO in the scale which softens at a relatively low temperature. It is further assumed that the molten-silicate phase discovered in the scale by Modin is on the one hand the cause of a strong erosion of the steel surface between the blisters, which was established in agreement with literature data, and on the other hand the reason why the adhesion of the scale is especially great at such points.

Finally, it is shown in a rough calculation that oxidation of the carbon content of the steel to CO yields a quantity of gas, which, in blisters of the size observed during the heating experiment, at 3 atm. excess pressure, should produce a tension in the wall of the blister of the order of 1·2 kp./mm.^{2} under certain assumed conditions. This question will be studied in greater detail during the continued experiments.

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Erbium and its alloys

E. M. SAVITSKII, V. F. TEREKHOVA and O. P. NAUMKIN

Data on metallic erbium, a rare-earth element, are limited as the metal has only recently been produced in pure form. No data on its alloys have hitherto been available. The following account of recent Russian work has been translated from 'Tsvetnye Metally,' January, 1960

ERBIUM (ATOMIC NUMBER 68) is a rare-earth element of the yttrium subgroup. The physical and chemical properties of metallic erbium have been little studied due to the fact that only very recently has a start been made on its production in a pure form.

In the literature there are certain data on the crystalline structure, thermal, electrical and magnetic properties of erbium.[1, 2] The mechanical properties of erbium have not been determined, apparently due to the small quantity of the metal produced in the pure form. There are no data of any kind in the literature concerning alloys of erbium.

The authors have carried out an investigation of the physical and mechanical properties of erbium and of its interaction with certain metals which are most frequently used in industry. The data of the research are the continuation of a cycle of investigations, carried out in the laboratory for alloys of rare metals of the Institute of Metallurgy of the Academy of Sciences of the U.S.S.R., on research into the physical and chemical properties of rare-earth elements and their alloys.[3-8]

For this study metallic erbium of 99·35% purity was used. The principal impurities in the metal, according to the data of the chemical analysis, are the following: Nd $<$ 0·1%, Ho $<$ 0·28%, Tu $<$ 0·1%, Y $<$ 0·1%, Th $<$ 0·2%, Ca $<$ 0·02%, Fe $<$ 0·01% and Cu $<$ 0·007%.

In the initial cast structure of metallic erbium, the coarse grains of the basic metal have relatively wide boundaries, along which are distributed the impurities present in the metal, and evidently oxygen in particular, the attention being drawn to the dark inclusions with varying outlines to be found primarily along the grain boundaries. The Vickers hardness of metallic erbium is 130–135 kg./mm.^{2}

A fracture surface of metallic erbium has a coarse crystalline structure with a grey colour. Remelting of erbium in an arc furnace with a water-cooled hearth in an argon atmosphere noticeably refines the grain of the metal. After remelting its hardness rises by 10–15 kg./mm.^{2}

Physical properties

The *density* of erbium was determined by the hydrostatic method and also by the method of X-ray analysis. On the basis of the data of the first method its density is 9·01 g./cm.^{3}, while the theoretical density by the data of the second method is 9·08 g./cm.^{3}

The *melting temperature* of erbium was determined by the droplet method in an apparatus assembled in our laboratory by V. P. Vinokurov.[9] A specimen of the metal of dimensions 7 × 5 × 4 mm. was heated by passing an electric current through tungsten clamps. The melting temperature was measured with an optical pyrometer on the occurrence of fusion in an aperture drilled in the specimen. The accuracy of measurement of the temperature by this method was ±20°C. The apparatus was calibrated with niobium, titanium, nickel and silver. The melting point of erbium, determined on three parallel specimens, equalled 1,550 ± 20°C.

The *buoyancy of metallic erbium vapour* was determined by the Knudsen method.[1] Vaporization from the Knudsen chamber was carried out on to a target (a mica platelet), which was suspended at one of the ends of the balance arm of a vacuum torsion balance with a sensitivity of 10^{-7} g., located in the same vacuum apparatus. Thus the rate of vaporization was determined from the increase in weight of the condensed metal on the target *in vacuo* without withdrawing the target into air (see the table).

The pressure of the vapour was determined from the equation:

$$P_{mm., Hg} = g/atW\sqrt{2rRT/M}$$

TABLE 1 *Experimental data on the determination of the buoyancy of metallic erbium vapour*

Tem. °C.	Holding time, sec.	Increase in weight on target, grams	$\frac{10^4}{T}$	P, mm. Hg	log P, mm.
1,100	$3\cdot3\times10^3$	41×10^{-7}	7·28	$2\cdot10\times10^{-4}$	−3·68
1,150	$4\cdot2\times10^3$	63×10^{-7}	7·03	$2\cdot58\times10^{-4}$	−3·59
1,200	$4\cdot8\times10^3$	238×10^{-7}	6·79	$8\cdot69\times10^{-4}$	−3·06
1,250	$3\cdot6\times10^3$	243×10^{-7}	6·57	$12\cdot04\times10^{-4}$	−2·92
1,300	$3\cdot9\times10^3$	928×10^{-7}	6·36	$43\cdot10\times10^{-4}$	−2·37

where a is the area of the effusion aperture, $1\cdot44\times10^{-3}$ cm.^{2};
t is the time of vaporization;
g is the weight of erbium in grams, vaporizing from the effusion aperture in time t; and
W is a factor taking into account the thickness of the jet:

$$\text{and } W=\frac{1}{1+0\cdot5\,(h/r)}$$

where h is the thickness of the jet, or 0·1 mm.; and
r is the radius of the jet, equal to 0·2 mm.

On the basis of experimental data, by the method of least squares an equation was obtained for the temperature relationship of the saturated vapour, measured in mm. of mercury column, in the following form:

$$\log P=\frac{14{,}146\pm469}{T}+6\cdot625\pm0\cdot315.$$

The value of the heat of vaporization calculated from these data was $\Delta H_{\text{vaporization}}=64\cdot75\pm0\cdot215$ kilocal./gram atom. The boiling point of erbium, calculated from a graph of the relationship between log P and $1/T$, is 2,650°C.

By X-ray structural analysis the lattice parameters of erbium were determined. The analysis was carried out by the powder method with copper radiation (Cu $K_{\alpha 1}>\lambda=1\cdot539$ Å) in a Debye-Scherrer chamber. The period of exposition was 24 hours. Before X-ray analysis, the erbium powder, wrapped in tantalum foil, was annealed in evacuated quartz ampoules at 300°C. for a period of 3–4 hours. On the X-ray diagram obtained 21 lines were detected. From calculation of the X-ray diagram it was established that erbium has a hexagonal, close-packed lattice with parameters, $a=3\cdot35$ Å, $c=5\cdot58$ Å and a ratio of the axes $c/a=1\cdot57$.

Mechanical properties

No data are available in the literature on the mechanical properties of erbium. We established its hardness, strength and plastic properties under tension and compression. All the mechanical properties were determined on specimens remelted in an arc furnace in an argon atmosphere. Due to the small quantity of erbium the tests for strength and plasticity were carried out on micro-specimens, which may perhaps have caused some increase in the strength characteristics. The hardness of erbium, measured on a Brinell apparatus with a 250-kg. load by means of a ball of 5 mm. diameter, was 95–100 kg./mm.^{2} The compression tests were carried out with a Gagarin test machine (a system developed in Russia); the specimens were in the form of a cylinder 5 mm. in diameter and 7 mm. high. The compression strength of erbium at room temperature is 78 kg./mm.^{2} and the plasticity (relative contraction) 22%.

Fracture tests were carried out on a Shevenar micro machine with photo recording of the extension diagram. Specimens for these tests were prepared on a watchmaker's lathe, and the diameter of the gauge length of 7·5 mm. was 1·5 mm. The strength and plastic properties, calculated from the extension diagram, had the following values: tensile strength 29 kg./mm.^{2}, limit of proportionality 19 kg./mm.^{2}, relative elongation not exceeding 1–2%, and no reduction in cross-section was detected. The strength and plastic properties of metallic erbium under tension are considerably lower than under compression due to the unfavourable diagram of stresses during extension.

During machining it was discovered that erbium of the degree of purity indicated above is a relatively brittle metal, and is friable when cut with a cutting tool. During the sawing of the specimens pyrophoricity was observed, but to a lesser extent than with lanthanum and cerium.

Alloys of erbium

Alloys of erbium with other elements have not been investigated by anyone hitherto. We made a study of the physical and chemical interaction of erbium with the principal components of industrial alloys—magnesium, aluminium, iron, titanium and tantalum. For this purpose alloys of the aforementioned metals with the addition of 5% erbium by weight were cast. The alloys of magnesium and aluminium with erbium were prepared according to the normal method of melting magnesium and aluminium alloys, in an electric furnace under a cover of flux in corundite crucibles. Alloys of the high melting point metals, iron, titanium and tantalum, with erbium were prepared in an arc furnace in an argon atmosphere. For the more accurate distribution of the erbium in the alloys remelting was repeated not less than three times. Investigations of all the alloys produced were carried out in respect of hardness and macro- and micro-structure, for which each specimen was cut into two parts along its centre.

The polished specimens of metallic erbium for microstructural analysis were prepared by the

ordinary method, but without the use of wetting, polishing substances, since under such conditions the surface of the polished specimen became tarnished. A mirror surface was obtained by finishing the polished specimens with velvet. The specimens were etched in air.

During the preparation of the *alloy of aluminium with erbium* it was shown that erbium in a quantity of 5% is completely dissolved in liquid aluminium. Microstructural analysis confirmed an even distribution of the phases over the whole area of the polished specimen. By microstructural analysis it was established that the alloy is di-phase. The secondary phase takes the form of a finely dispersed eutectic, distributed along the grain boundaries. Measurement of the microhardness of the alloy showed that as a result of the addition of 5% erbium to aluminium a considerable increase in the hardness of the latter is obtained. Thus, where the Vickers hardness of pure aluminium is 20 kg./mm.^{2}, that of the alloy with 5% erbium is 36 kg./mm.^{2} These data permit the assertion that erbium, like other rare earth elements, can be a strengthening addition to aluminium alloys. Apparently the composition diagram of aluminium with erbium is similar in its structure to the composition diagrams of aluminium with other rare earth metals with which we are already familiar.[10, 11]

The preparation of *alloys of magnesium with erbium* was accompanied by considerable experimental difficulties, since erbium is very difficult to dissolve in liquid magnesium due to the great difference in specific gravity, and especially at melting temperatures. During the melting of magnesium under flux (KCl and NaCl), erbium reacted actively with the flux, and a considerable part of the erbium passed off into the slag. The melting of alloys of magnesium with erbium was carried out in a hermetically-sealed vessel of argon under pressure, in which the temperature of the alloy was successfully raised to 1,100–1,200°C. Due to the fact that the vessel was sealed and stirring of the alloy was complicated, the alloy produced was uneven in its composition. By microstructural and chemical analyses it was established that the lower part of the ingot was enriched in erbium to a greater extent. Chemical analysis showed an average content of 2·5–3% erbium in this part of the ingot, while in the upper part of the ingot the erbium content was 0·9–1·0%. The erbium is distributed both along the grain boundaries and also in the form of dark, rounded inclusions in the body of the grain. On the basis of the data of the analyses it may be suggested that the limit of solubility of erbium in magnesium does not exceed 0·5–0·7% by weight. The hardness of the alloy of magnesium with 0·9% erbium is 68 kg./mm.^{2}, while that of pure magnesium is 53 kg./mm.^{2}

In the work which we carried out with A. I. Markova on alloys of magnesium with yttrium, it was established that this relatively high melting-point metal (m.p. 1,530°C.) has low solubility in liquid magnesium. In order to produce homogeneous alloys prolonged holding times in the furnace in the liquid state are required, of the order of 2–3 hours at a temperature exceeding 1,000°C. Evidently the same melting conditions are necessary for the preparation of alloys of magnesium with erbium. Alloys of magnesium with yttrium and erbium have composition diagrams of the eutectic type with low solubility in the solid state, of the order of 1–2%, and the presence of chemical compounds at greater concentrations of yttrium and erbium.

For alloys of magnesium with erbium, just as with those of aluminium with erbium, it may be expected that the metals will be effectively strengthened as a result of small additions of erbium.

By analyses of the macro- and micro-structures of *alloys of iron* with 5% erbium by weight, it was found that alloying of the components takes place with the formation of a di-phase structure. Erbium greatly refines the iron grain, and at the content indicated is distributed along the grain boundaries in the form of a peritectic. Under such conditions the hardness of the alloy iron attains from 130–180 kg./mm.^{2}

During the melting of *erbium with titanium* good alloying of these elements was revealed. On the introduction of 5% erbium to the alloy, the erbium was partly dissolved in the titanium, and the residue was distributed along the grain boundaries in the form of dark inclusions. The hardness of titanium with 5% erbium is 200–220 kg./mm.^{2}, while the hardness of pure titanium, remelted in an arc furnace in an argon atmosphere, is 130–140 kg./mm.^{2} Erbium is a good modifier and hardener of titanium alloys, for it noticeably refines the grain, and increases the hardness, of titanium.

Tantalum is one of the most widely employed materials which can be used for the manufacture of crucibles for the melting of erbium and other rare earth elements and alloys. With the aim of determining the interaction of tantalum with erbium, an alloy of these metals containing 5% erbium was prepared. Analyses of the macro- and micro-structures confirmed the complete stratification of these materials and their failure to alloy in both the liquid and solid states.

Conclusions

The physical and chemical properties of metallic erbium with a purity of 99·35% were determined.

The hardness of cast erbium is 95–100 kg./mm.^{2}, the limit of proportionality 19 kg./mm.^{2} and the

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Electron microfractography

New technique for examining fractures

Fracture surfaces of metals can now be examined at magnifications up to ×50,000 by the electron microscope. This technique, termed 'electron microfractography,' may become an important tool in failure analysis; it promises to reveal many hitherto undisclosed details associated with the various failure phenomena. The following account is based on an article in 'Metal Progress,' May, 1961, by Mr. Austin Phillips and Mr. Guy V. Bennett, materials research engineer and head of Metallurgical Research, respectively, Santa Monica Division, Douglas Aircraft Co. Inc., Santa Monica, California, U.S.A.

THE STUDY of metal fractures by visual observation and by the optical microscope is perhaps one of the oldest techniques known to metallurgists. Because of the efforts of investigators such as C. A. Zapffe, this type of examination has become continually more valuable through the years. As a result, the metallurgist of today can identify and interpret much more accurately the various causes of metal failure.

It is significant, however, that this improved insight into fracture mechanisms has come with the improvement in design and manufacture of microscopes. The wavelength of visible light imposes a physical limitation on resolution and as a result an impasse has been reached in recent years. At top magnification, the light microscope is seriously limited as to resolution and depth of focus for examining fracture surfaces.

Fortunately, we can turn to a new tool, the electron microscope. Because it can provide a greater depth of focus and a higher resolution, this device is well suited for the examination of fracture surfaces. Furthermore, there is the very considerable gain in magnification.

Surface replicas technique

There is, however, the drawback that a metal specimen of appreciable thickness cannot be examined directly under the electron microscope and thin replicas of the surface must be produced.

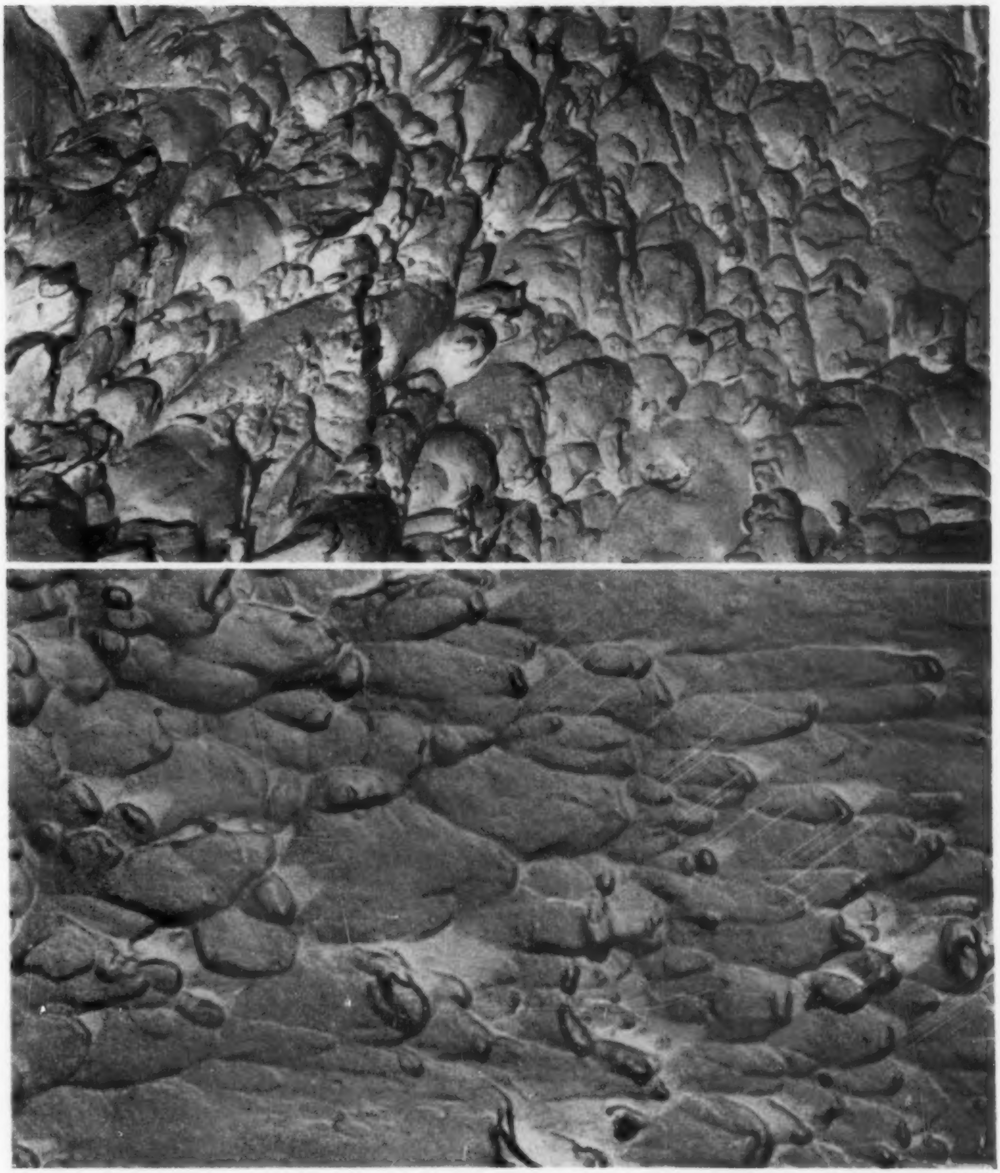
At Douglas, techniques have been devised, and are continually being improved, for obtaining replicas from fracture surfaces, a difficult task since they are usually quite rough. (A polished surface is normally employed in electron-microscope studies of microstructure.) When a successful technique for replication* had been devised, engineers began to study fractures produced by various failure mechanisms. After learning the characteristic topography of fractures produced by known mechanisms, they then applied the technique to determine the cause of failures when other methods were inconclusive. Some of the observations made in these studies form the basis of this article.

Studies of various fractures

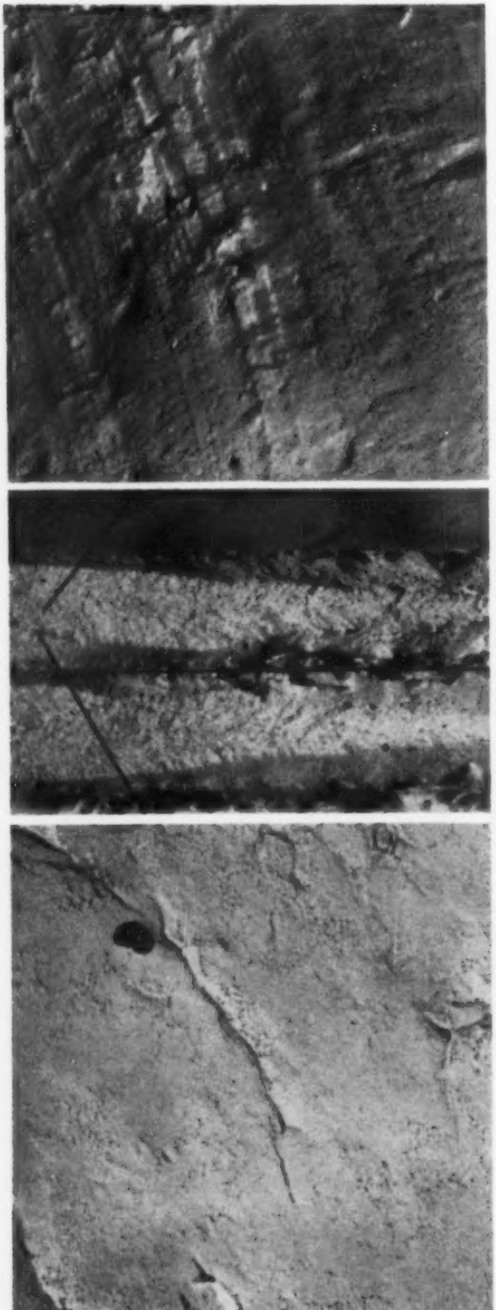
Ductile fractures have some unusual features, as the fractographs in fig. 1 show. Fig. 1*a* represents the centre portion of a cup-and-cone fracture of a tensile specimen of A.I.S.I. 4340 steel quenched and tempered to a tensile strength of 260,000 lb./sq. in. The surface, divided into many small areas termed domains, is characteristic of fracture surfaces in which much plastic flow occurred before rupture. Fig. 1*b* shows a fractograph of a surface of a shear specimen of the same steel. In this instance, the domains are extensively elongated in the direction of the shearing force, rather than being randomly oriented as in the

* To prepare the replica, a thin sheet of cellulose acetate (softened in acetone) is applied to the fracture, forming a plastic negative. When this negative is dry, it is stripped from the surface and shadowed with chromium vapour (in vacuum) 45 deg. to the replica plane. Next, carbon is deposited normal to the replica face.

The replica specimen is then cut into small squares, and the plastic negative subsequently dissolved away in acetone. This leaves square sections of a preshadowed positive replica of carbon floating in the acetone bath. After these sections are strained from the liquid on a 200-mesh copper screen and washed in vapours of acetone for several hours, they are ready to be examined.



1 *Tensile and shear fractures in test bars of A.I.S.I. 4340 heat treated to 260,000 lb./sq. in. The many small areas into which the surfaces are divided are called domains; they characterize fracture surfaces which have undergone much plastic flow. In the shear specimen* (BOTTOM) *the domains are elongated. This characteristic can sometimes be used to determine the direction of force.* **a** TOP × 13,700 **b** BOTTOM × 27,000



2 LEFT *Delayed failure in hydrogen-embrittled A.I.S.I. 4340. The fracture reveals hydrogen-indication sites* (bottom) *which appear to be voids at sub-grain boundaries. The propagation lines* (top) *indicate that fracture growth is discontinuous in certain areas. Fracture surface,* × 10; *micrographs,* × 27,000

3 ABOVE *Delayed failure in a ring embrittled by hydrogen during cadmium plating. Apparently, the smaller amount of hydrogen in this specimen (compared to that in the test bar illustrated in fig. 2) produces a different mode of fracture. In this instance, the 'rock-candy' surface indicates intergranular failure,* × 5,700

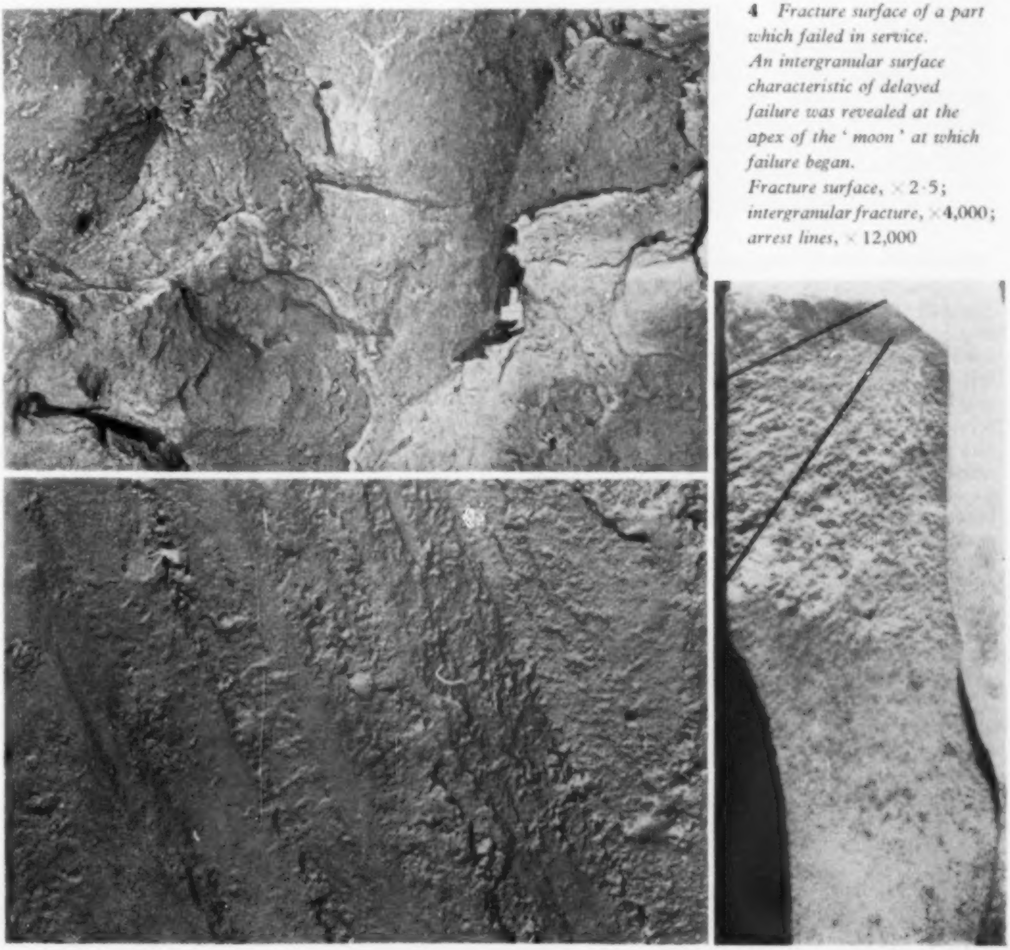
tensile specimen. This observation can sometimes be useful in determining the direction of fracture.

Fatigue fractures also have distinguishing characteristics. One need only look at the fracture at low magnification to see that the part failed in fatigue. However, when the fracture is examined with higher magnification, additional rings or 'beach marks' are observed between those visible at the lower magnification. Going one step further, when the fracture is examined under the electron microscope, smaller rings or arrest lines can be seen between those previously visible. The spacing between the arrest lines increases with the distance from the origin of failure.

Hydrogen embrittlement

In high-strength steels (above 200,000 lb./sq. in.), hydrogen often introduces a type of failure which goes by such names as static fatigue, delayed cracking, and delayed failure. Whatever the name, the fractures produced by this mechanism have been studied extensively under the electron microscope.

Fig. 2 shows some of the interesting features observed on the fracture of a notched specimen of A.I.S.I. 4340 that had been cathodically charged with hydrogen before being statically loaded. Failure occurred in 27 h. As the fracture surfaces at ×10 show, the crack began at the left side of



4 *Fracture surface of a part which failed in service. An intergranular surface characteristic of delayed failure was revealed at the apex of the 'moon' at which failure began. Fracture surface, ×2·5; intergranular fracture, ×4,000; arrest lines, ×12,000*

the specimen and propagated toward the right. Where the crack formed and grew slowly, the fracture contains two distinguishing features: hydro-indication sites and propagation lines. The existence of the latter feature suggests that this type of fracture is discontinuous, at least at those portions of the fracture where they appear. However, only a small portion of the surface in the area of slow growth contained propagation lines; the remainder contained hydrogen-indication sites. At × 27,000, these sites appear as voids at what are believed to be subgrain boundaries in the steel.

When there is only a small amount of hydrogen present at the time the same steel (A.I.S.I. 4340) is under static stress, the fracture surface appears quite different, as fig. 3 shows. In this instance, the specimen received hydrogen while being cadmium plated by a low-hydrogen process. After plating, it was baked for 23 h. at 200°C. Then, while a static stress of 170,000 lb./sq. in. was applied, the specimen was intermittently immersed in tap water until it failed. In this instance, the fracture surface was highly faceted. Obviously, the appearance of the fracture produced by hydrogen embrittlement is affected by the amount of hydrogen present as well as the magnitude of the static stress.

Application of the technique

This technique is by no means merely a laboratory curiosity. When used for analysing several failures, it has provided conclusive identification of the mechanism causing them. Consider as an example the fracture surface of a portion of a structure that had been fatigue tested under simulated service conditions. Although loading was cyclic and fatigue failure should occur, the fracture contained none of the characteristic marks common to fatigue. (This was undoubtedly due to the high-stress, low-cycle nature of the test.) However, examination under the electron microscope proved that it was indeed a fatigue failure, the multiple origins of failure all containing arrest lines.

Another example is shown in fig. 4. In this instance the part (A.I.S.I. 4340 heat treated to 260,000 to 280,000 lb./sq. in.) failed in service. As can be seen, failure began at the ' moon ' shown at the top of the fracture face. However, examination of this zone at × 50 did not reveal any evidence of fatigue or features characteristic of other failure mechanisms. When the fracture surface was examined under the electron microscope, the cause of failure became apparent. The apex of the moon, the point of crack initiation, had the ' rock-candy ' surface characteristics of delayed failure, and the remainder of the moon possessed arrest lines. From this investigation it was obvious that hydrogen embrittlement was responsible for the failure. Once the crack formed, it propagated by fatigue to the point where rupture occurred.

In conclusion, electron-microscope studies of fractures produced by various failure mechanisms has enhanced the knowledge of deformation and fracture modes. ' Electron microfractography ' has become an important tool in failure analysis, and promises to reveal many of the undisclosed details associated with the various failure phenomena.

Erbium and its alloys

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ultimate tensile strength 29 kg./mm.[2] The compression strength is 78 kg./mm.[2] and the contraction under compression 22%. The melting point is 1,550 ± 20°C., the boiling point 2,650 ± 50°C. and the heat of vaporization 64·75 kilocal./gram atom. X-ray analysis confirmed the hexagonal structure of erbium with parameters: $a = 3{\cdot}55$ Å, $c = 5{\cdot}58$ Å, $c/a = 1{\cdot}57$. The density of the metal is 9·08 g./cm.[3]

It was established that erbium in a quantity of 5% alloys with aluminium, magnesium, iron and titanium with the formation in all instances of di-phase compositions of the eutectic or peritectic type. In all the alloys investigated erbium is a good modifier and hardener. Erbium will not alloy with tantalum. Since erbium is a very rare and expensive metal, its use for the alloying of basic industrial alloys does not seem feasible. Possible spheres of employment of erbium may be the manufacture of instruments, electronics and other branches of technology, where it may be possible to make use of the special physical properties which distinguish erbium from the circle of other rare-earth metals, for instance its ferromagnetism, optical properties, etc. In the future, research works on erbium and its alloys should be extended in the direction of studying the whole range of physical and chemical properties with the aim of discovering precision alloys with special physical properties.

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Electron-microscope studies at the N.P.L.

The Metallurgy Division of the National Physical Laboratory at Teddington continues to make increasingly good use of its 100-kV. electron microscope. Direct transmission, by means of the thin-film technique, has proved particularly suitable for studying the precipitation of phases from solid solutions. New and detailed information of the processes that occur during the ageing of steel is being obtained by this method. The following notes describe some of the work seen at the recent Open Days at the laboratory

DURING LAST YEAR the electron microscope had begun to be used more extensively by the Metallurgy Division as a whole and is now in operation for virtually the whole of the working day. This position has come about partly because the microscope clearly helps with the solution of numerous metallurgical problems and partly because of a continual improvement in the techniques of making specimens suitable for examination.

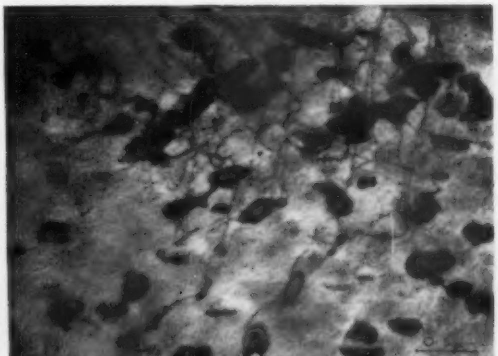
The study of the arrangement of dislocations in iron previously described has been completed and is being followed up in two ways. Firstly, as there are grounds for believing that the nature of the dislocations can be fairly quickly discovered if the foil specimen can be tilted inside the microscope, a goniometer stage small enough to fit inside the microscope has been designed. In addition, two devices, one to enable the specimen to be strained in the microscope, and the other to enable it to be heated in the microscope, have been made. Secondly, as the junctions made between dislocations must impede their movement, calculations are being made of the strength of this resistance. At a recent conference on crystallography at Cambridge it was possible to compare the preliminary results with similar results obtained in Paris. The agreement was very satisfactory, and more comprehensive calculations are being made using a computer in Mathematics Division.

Ageing of iron: precipitation on dislocations

Most of the increase in strength of alloy steels over pure iron is believed to be due to fine dispersions of precipitate particles, but many features of the strengthening mechanism of these particles could not be investigated until recently, since the particles were below the resolution of the optical microscope.

1 *Transmission electron micrograph of iron-carbon alloy (0·05 wt. % C) quenched from 690°C. and aged 18 months at room temperature. The dendritic precipitate is iron carbide that has nucleated on stationary dislocation*

2 *Transmission electron micrograph of iron-nitrogen alloy (0·01 wt. % N) quenched from 550°C. and aged three days at 100°C. and then lightly strained. The iron nitride precipitate can be seen to have acted as obstacles to moving dislocations* [*Crown Copyright reserved*



With the electron microscope, and a recently developed technique, these particles can be studied *in situ* in the metal. In this technique, the specimen to be examined is thinned by electropolishing until it is about 1×10^{-5} in. thick; it is then transparent to the electron beam of the 100-kV. electron microscope. This enables both the precipitates and the lattice defects known as dislocations to be seen. Plastic flow in metals takes place by the movement of these dislocations and where they can move easily, as in a pure metal, the metal is soft. It is believed that precipitate particles confer strength by acting as obstacles to dislocations, and it is expected that many details of the interaction can now be studied.

The present investigation has shown that, in an iron-carbon alloy, precipitation occurs predominantly on dislocations and that at room temperature and 100°C. the precipitate is mainly epsilon carbide, a close-packed hexagonal phase growing on $\{100\}$ planes in a $\langle 100 \rangle$ direction. In an iron-nitrogen alloy the precipitate occurs to a large extent between dislocations and grows on $\{100\}$ planes in the form of discs as the ordered body-centred cubic structure $Fe_{16}N_2$. Dislocations have been observed to wrap round these obstacles and this is believed to be responsible for the increased resistance to deformation. These studies are being extended to commercial steels, and it is clear that the additional elements present in these can affect the precipitation processes.

In a relatively brittle, strain-ageing steel more precipitate was found and the dislocations moved less readily under stress inside the microscope than in a relatively tough, non-strain-ageing steel. These observed differences are in keeping with the difference in mechanical behaviour and indicate that a new and important field is accessible to study.

Further observations of the structural changes in gold during single and repeated application of stress have been made and have shown that repeated application of stress is associated with an unusually high density of stacking faults. Metal with a high density of faults has the interesting property of dissolving more rapidly than the matrix during electrolytic preparation of specimens of foil for use in the electron microscope.

A new investigation of creep in iron has been commenced in which dislocation patterns produced during creep under a range of temperatures and stresses are being examined. It has been found that relatively open dislocation patterns are formed, which permit counts of dislocation density to be made with useful accuracy. This introduces a highly desirable quantitative element into the work.

The foils used in electron microscopy of metals are extremely thin, and it would be useful to be able to examine more substantial samples of metal. Consequently, the feasibility of construction of a high-voltage electron microscope (400 kV.–1 MV.) and its possible application in metallurgy is being considered.

Surface energy and composition

Measurements of the surface energy of copper and copper-antimony alloys have been checked and consolidated. It has also been found that with the electron microscope accurate measurements can be made of the meeting angles at individual junctions between twin and grain boundaries. A series of measurements has been undertaken to ascertain whether antimony causes a systematic variation of the angle and hence of the twin boundary energies.

Goniometer stage for the electron microscope

To obtain high-quality thin foil electron micrographs it is necessary to tilt the specimen critically. The existing tilting-stage supplied with the microscope is too restricted in its action, so a completely new stage has been designed and constructed. The stage should allow the direct determination of the Bergers vectors of dislocations, the determination of the crystallography of precipitates with respect to the parent matrix, and the facility for producing good-quality stereographic pairs of micrographs.

To avoid any shift of the observable specimen field when a specimen is tilted, the design of the goniometer stage was based upon the simple kinematic system of locating a ball in an inverted cone, which provides a method in which specimens, mounted to intersect the ball centre, may be tilted without shake.

In this application a hemisphere is used. Tilting is effected by the action of four slender push pins angled at 15° which contact the diametric plane of the hemisphere. By tilting the hemisphere through approximately $\pm 22°$ about each of two horizontal axes at right angles to each other, a composite tilt of $\pm 30°$ is obtained. Each push pin makes contact at its upper end with the horizontal end face of an actuating rod. The horizontal end faces of each of the rods allow free movement of the specimen carriage without interference with the specimen tilt.

The upper end of each of two of the actuating rods make contact with a conical portion of individual horizontally disposed shafts each of which is forced by an axial spring to follow the movement of the spindle of a commercial micrometer. A deadweight is placed on the upper end of each of the other two rods in a manner which, although avoiding undesirable excessive loading on the hemisphere, ensures that the tilting movement of the hemisphere follows the micrometer-actuated rod when the latter is retracted.

Avoidance of distortion in heat treatment

K. SACHS, Ph.D., M.Sc., A.I.M.

*Three types of distortion are distinguished: Change in volume; change in shape; and warping. Their characteristics, causes and prevention are discussed**

THE FORMAL DEFINITION of distortion is 'a change in shape or dimensions caused by the balancing of internal stresses, *i.e.* the reduction to zero of the resultant of all the internal stresses.' Thus distortion is the result of differences in the natural lengths of adjacent layers of a given component.

In the author's youth, schoolboys had the bad habit of devising definitions in a somewhat different style—'distortion is when. . . .' Although quite deplorable, of course, it is sometimes easier to understand. The simplified definition in this instance would be: 'Distortion occurs when one part shrinks or expands more than another so that they no longer fit together.'

As an example, the two parts of a bimetal strip (fig. 1) are equally long at room temperature but they differ in coefficient of expansion. When the strip is heated, one part expands more than the other. If they were separate we should have two straight strips of different length. But they are joined, so the short part is in tension, the long part is in compression and the assembled strip is bent. When the strip is allowed to cool again the two parts are again equally long and the strip straightens out. If the strip has been overheated so that the stress is greater than the elastic limit, plastic deformation will occur, the shorter part will be stretched a little instead of bending the strip further. When the strip is cooled after this, the natural length of the part that has previously been on the inside of the bend has been increased by the plastic stretching, so that at room temperature the strip is bent in the opposite direction. The longer, plastically stretched part is now in compression, the part that had retained its original length is in tension. Thus, plastic deformation at temperature has led to a reversal of stress distribution and of distortion on cooling. We shall meet this again.

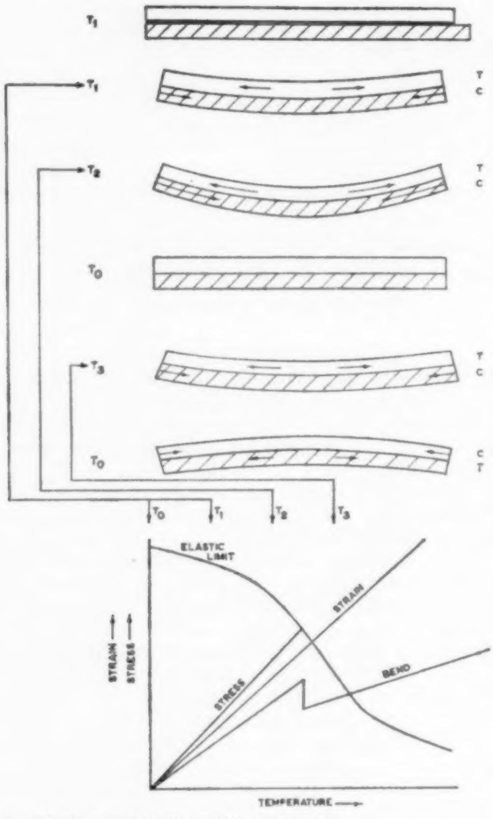
In practice, three types of distortion are distinguished (fig. 2): (1) Change in volume; (2) change in shape; and (3) warping.

(1) *The change in volume* is associated with the constitutional changes occurring in heat treatment. When a block of copper is heated, its volume increases, when it cools it shrinks. Unless the stresses produced by the temperature gradients cause plastic deformation the volume after cooling should equal that before heating.

With steels, volume changes due to phase transformations are superimposed on thermal expansion and contraction, but in principle the same applies: unless plastic deformation intervenes, the volume of an annealed structure should not be altered by a further annealing treatment. In practice, of course, the steel undergoes a sequence of different heat treatments and the hardening of an annealed structure to form martensite causes a considerable increase in volume. In principle, this is predictable, from experiment if not from the literature, and while it is of great practical importance, it need not greatly concern us here. The subject is complicated by the fact that hardening does not always produce a uniformly martensitic structure. The final volume depends on the densities of the different constituents and their distribution in the block of steel.

(2) *Symmetrical changes in shape* are caused by internal stresses, if they are symmetrically distributed in the component. As we shall see in more detail later, the thermal stresses associated with heating and cooling (without transformation) are severe enough to cause plastic deformation: flat faces will bulge; discs will grow thicker and shrink in diameter; bars will grow shorter and their diameter will increase. In steels internal stresses may

*Article based by the author on his lecture given at the Birmingham College of Advanced Technology last January in the series 'Modern developments in the theory and practice of steel heat treatment.' The author is Head of Research Metallurgy Section, G.K.N. Group Research Laboratory, Wolverhampton. The article will be concluded next month. Articles based on other lectures in the series will be published in future issues of METAL TREATMENT.



1 *Heating and cooling of bi-metal strip*

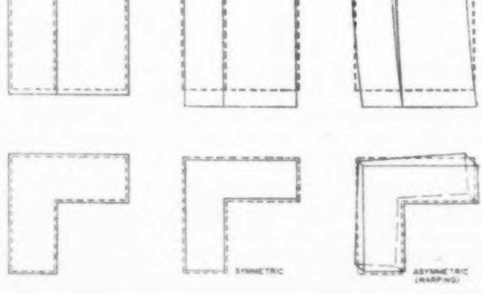
occur as a result of heat treatment even without plastic deformation, although in general plastic deformation also occurs.

If we consider a large block with a fully-annealed structure subjected to a hardening treatment that produces martensite at the surface and intermediate transformation products further in, there will be a gradient of increased expansion between the centre and the surface. The surface will be in compression, the centre in tension. The presence of retained austenite would have a moderating effect on the expansion of the martensite and thus on the compression in the surface, but if austenite is retained in the centre as well (and slower cooling may help to stabilize austenite) the expansion in the centre will also be reduced, the 'natural length' or volume will be less and the tension imposed on it by the pull of the expanded surface layers will increase in severity.

(3) *Warping* is an asymmetrical change in shape and can be produced by any of the causes of distortion if they operate unevenly. It occurs most frequently in components of asymmetric shape or of symmetrical shape with severe changes of section. It is also caused by uneven heating or cooling, sagging, sudden chilling of thin sections by cold tongs, dropping hot components on the floor, and other forms of bad heat-treatment practice.

Changes in shape and internal stresses can be presented in terms of assembled springs. Each spring in fig. 3*a* represents the natural length of a layer of metal but in a solid block of metal they are locked together, say with a bar across the top. If the natural lengths of the separate parts are equal there is no internal stress and no distortion. But suppose the block is cooled from a high temperature, then a temperature gradient is set up and at any instant the outer layers have contracted more than the inner ones.

The natural lengths are shown by the springs in fig. 3*b*. The solid block is symmetrical; the spring assembly in fig. 3*c* shows that the total length is intermediate between those of the layers; to achieve this the outer springs have to be stretched and the inner ones squashed. Thus the outer layers are in tension, the inner ones in compression. If these stresses are less than the elastic limit, then by the time the block has cooled to a uniform temperature, the natural lengths are equal again, and the internal stresses have relaxed.



2 *Types of distortion (dotted lines, before heat treatment; full lines, after heat treatment)*

However, if the stresses are high enough to cause plastic yielding, then the surface will have stretched or the centre will have been upset, the natural lengths at room temperature are unequal, *i.e.* the outer layers are longer than the central ones, so that the surface is in compression and the centre in tension. Thus, if plastic deformation occurs on cooling, it produces a system of internal stresses in the cold block the exact reverse of the stress system during cooling. If the cooling conditions are asymmetrical, the internal stresses will be unevenly distributed and the component warps.

It is not necessary, however, for the component to be asymmetrical to produce warping on quenching. Consider a wheel with heavy rims and boss and a thin web, as in fig. 4. The web cools first, but cannot contract because of the constraint imposed by the heavy sections. As a result it stretches plastically. When the web reaches the martensite temperature and begins to expand, the rim has shrunk considerably and a greatly extended web has to fit into a contracted rim. Naturally, it buckles. When the rim expands at the martensite point the distortion is reduced somewhat. The shape of the buckle can follow either of the courses sketched, though the first one seems more probable.

Factors involved in distortion

Having discussed the mechanism of distortion we go on to consider the various factors determining its occurrence and severity. Since distortion is a change in shape caused by stresses set up by changes in dimensions of adjacent layers in a solid component, the most important factors are: (1) Extent of the dimensional change; (2) the stress associated with a given dimensional change; and (3) the stress at which plastic yielding occurs.

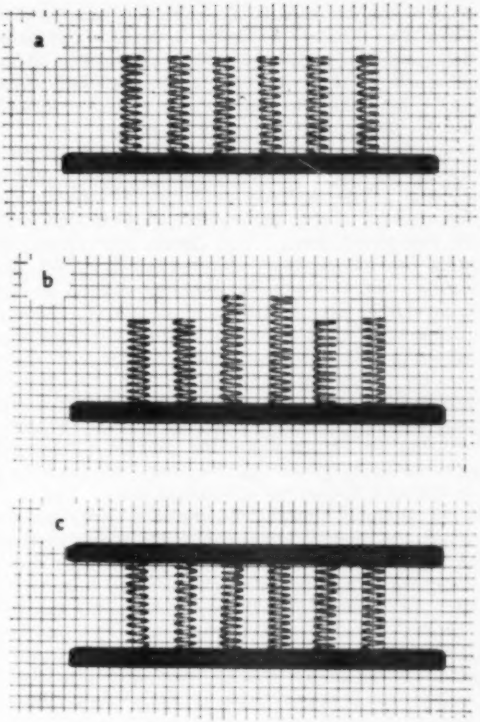
In addition, distortion may be caused by: (4) presence of internal stresses from previous operations, and (5) external forces.

Let us take these factors one at a time:

(1) *The extent of the dimensional change* at any instant depends on the difference in temperature between different parts of the component. This is obviously a function of the temperature gradient, which is determined by the size of the component, the choice of quenching medium, the temperature and heat capacity of the furnace on heating, and by the thermal diffusivity of the steel. Thermal diffusivity is the thermal conductivity divided by the density and specific heat. The latter are constants and the thermal conductivity depends on the composition of the steel and the temperature.

The dimensional change also depends on the coefficient of expansion. This does not vary much between one steel and another.

Transformation stresses are determined by the dimensional changes occurring at the A_3 point on heating and at the M_s point on cooling. This is a function of the composition. The volume increase on transformation to martensite is greater the lower the M_s temperature, *i.e.* the higher the carbon content.



3 *Spring assembly model of thermal stresses in cooling block of metal*

Other elements also influence the dilatations. Kenneford has studied the effect of different elements and found that Cr increases the volume change while Mo and Si lower it[1], he has developed a steel containing 2% Si and 0·75% Mo which has excellent resistance to thermal stress cracking, a U.T.S. of 120 ton/sq. in. with good ductility and impact toughness and considerable resistance to softening up at 550°C.[2] Obviously, however, there are many applications where Cr containing steels have to be used in spite of the higher volume change on transformation.

Further variations in the dimensional changes occur when there are differences in composition or structure between adjacent areas, as in carburized steels, or in the presence of segregation, variations in degree of hot working, etc.

(2) *The stress associated with a given dimensional*

change can be calculated from the modulus of elasticity. Young's Modulus is virtually the same for most steels that can be heat treated, about 30×10^6 lb./sq. in. at room temperature and about 22×10^6 lb./sq. in. near A_1; for austenite around 800°C. the value is 18×10^6 lb./sq. in.

(3) Severe distortion occurs when the stresses set up by the dimensional changes cause *plastic yielding*. This depends on the stress system, *i.e.* the stresses in the three principal directions, and on the elastic limit. The elastic limit decreases with the temperature; its general level and the detailed variation with temperature depend on the composition and structure of the steel. In the temperature range of the martensite transformation, austenite will yield much more readily than martensite. Thus the expansion of the outside of a block that forms martensite first will stretch the austenite in the centre; when the latter transforms, the tension imposed on the outside cannot be eliminated by plastic yielding but remains locked in the steel in the form of internal stress.

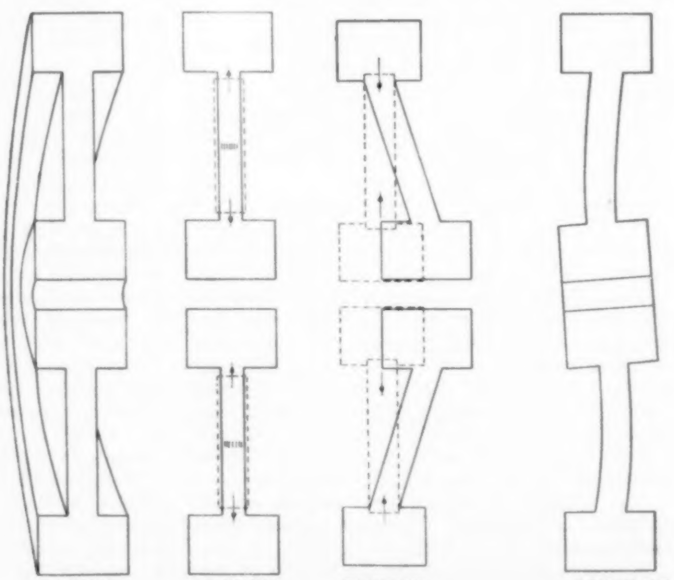
(4) *Internal stresses from previous operations* are eliminated at the hardening temperature, so they cannot influence distortion on quenching. However, they may cause distortion during heating up and if the component is already distorted when it reaches the hardening temperature it can only make matters worse. The origin of internal stresses may be hot or cold work (in practice cold straightening is a particularly likely cause), heavy machining, or cooling stresses from previous heat treatments. Quenching and transformation stresses due to hardening may cause distortion on heating for tempering.

(5) *External forces* are not often deliberately applied in heat treatment, but gravity is too often ignored. It is important that heavy components should be supported without sagging and if jigs are used great care must be taken in their design. It is worth remembering that martensite formation is favoured by tensile stresses and discouraged by compression, so that a non-uniform stress distribution imposed in quenching may produce distortion due to the non-uniform progress of the martensite transformation in the component.

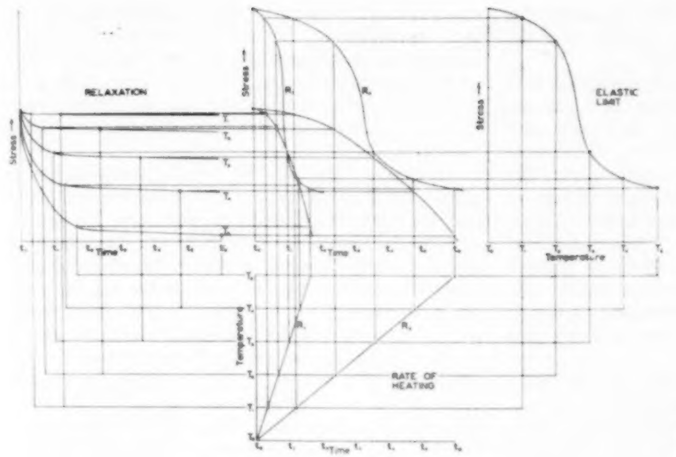
It is now proposed to consider the three types of distortion in turn, to run through the heat-treatment sequence and to discuss what is likely to happen in each operation.

Change in volume

Heating for hardening The formation of austenite leads to a sharp and rapid decrease in volume. In hardening the matrix is entirely converted to austenite, but in many steels alloy carbides are left as a second phase. The higher the austenitizing temperature the more carbide goes into solution, and this may increase or decrease the volume change depending on the influence of the alloying element on the lattice parameter and thus the density of the austenite. Carbon itself is in inter-



4 *Distortion of wheel*



5 *Variation of internal stresses during heating*

stitial solution in austenite and should presumably increase its lattice parameter, *i.e.* reduce the contraction.

Quenching The formation of martensite produces an expansion and we have already seen that its extend depends on the M_s temperature, which is controlled by the C content, and is also influenced by alloying elements. Incomplete transformation, *i.e.* the formation of bainite or pearlite, greatly reduces the expansion. Retained austenite does not expand until it decomposes, and it is possible to balance the expansion due to martensite formation by a judicious admixture of retained austenite; sometimes this has surprisingly little effect on the hardness—if the martensite itself is rich in carbon and very hard, if there is plenty of alloy carbide, and if the structure is fine and uniformly distributed. The proportion of martensite to other products depends on the hardenability of the steel and the cooling rate. The hardenability is principally a function of composition, but we must not forget that it is also profoundly influenced by the grain size of the austenite, so that in a given component the hardenability can be increased by raising the hardening temperature.

The amount of retained austenite depends on the M_f temperature, *i.e.* on the stability of austenite. This is virtually independent of the cooling rate, although in special cases slower cooling is said to stabilize austenite a little, but the main variables favouring austenite stability are a high carbon and alloy content and a high austenitizing temperature; the two are related because at a higher temperature more of the alloy carbides go into solution in the austenite.

Cold treatment is sometimes carried out to transform retained austenite to martensite and is accompanied by a corresponding expansion.

Tempering decomposes martensite and thus causes a contraction, which is generally greater the higher the tempering temperature. However, it may also transform retained austenite, leading to an expansion. At the tempering temperature the product is bainite and the expansion is not as great as in the case where the austenite precipitates carbides and transforms to martensite on cooling.

Symmetrical change in shape in heating and quenching

Under this heading I propose to consider the distortions caused by the stresses generated by the dimensional changes discussed above. Transformation stresses have their worst effect on quenching, thermal stresses may act equally on heating or cooling, but the relief of internal stresses occurs only in the heating cycle; once the heat-treatment temperature is reached the residual stresses have been relieved, whether the process has caused distortion or not.

In considering distortions occurring on *heating for hardening*, therefore, pride of place must go to distortions caused by the relief of residual stresses.

On heating up for any heat treatment distortion will occur if the rate of heating is so fast that the steel yields before the stress is relaxed. In fig. 5 a family of relaxation curves is shown on the left; the higher the temperature, the lower the stress retained after various periods. The graph on the right shows the variation of elastic limit with temperature in an equally schematic way. Underneath the main graph is another auxiliary diagram of temperature versus time, indicating heating rates.

These are used to construct curves showing the variation with time of the internal stresses and the elastic limit at two rates of heating.

There are a number of oversimplifications in this construction, not least the heating rate curves, which are not linear in practice, and will vary between surface and core. Moreover, the relaxation will be slightly less than indicated because the points on the graph correspond to stress relaxation under conditions of constant temperature. However, the main point is clearly demonstrated: at slow heating rates the internal stress is relaxed before a temperature is reached at which the elastic limit coincides with the prevailing stress; at fast heating rates the curves may overlap and distortion may occur.

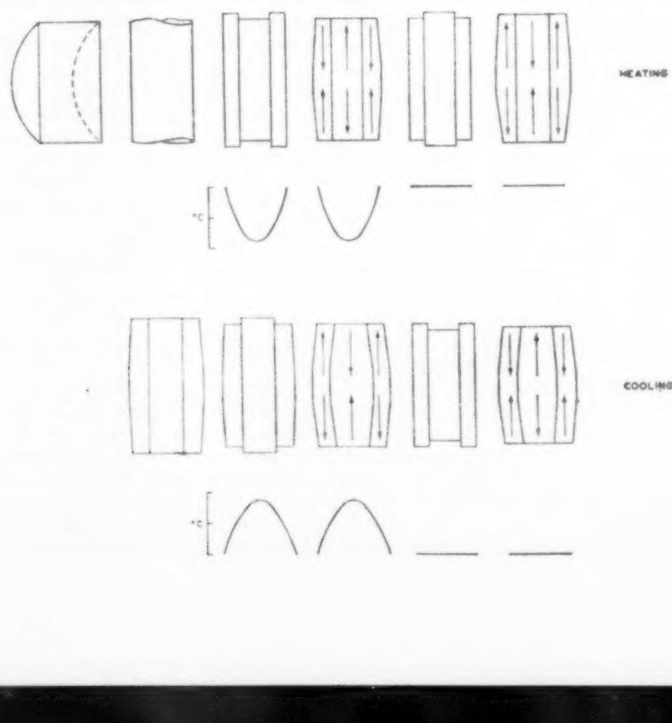
The obvious remedy is to ensure a reasonably slow heating rate, or to stress-relieve the component before hardening. A stress-relief heat treatment may also have to be fitted in during a heavy machining sequence, because the removal by machining of metal carrying elastic stresses will distort the remainder. As with heating rates, the stress-relief temperature must be one at which the elastic limit remains sufficiently high to allow the stress to relax without plastic yielding.

Thermal stresses may also produce distortion on heating. Fig. 6 shows the two outer layers and the core of a metal block during heating up for heat treatment. The outside is hotter than the centre and its natural length is greater. Thus the outside will pull against the centre, will try to stretch the centre, while the centre will restrain the expansion of the outer layers. Clearly, the surface is in compression, the centre in tension; if these stresses are high enough, plastic yielding occurs and there can be no doubt where; the elastic limit is lower in the hotter surface zone and it will yield first; the compressive stresses will tend to upset the block.

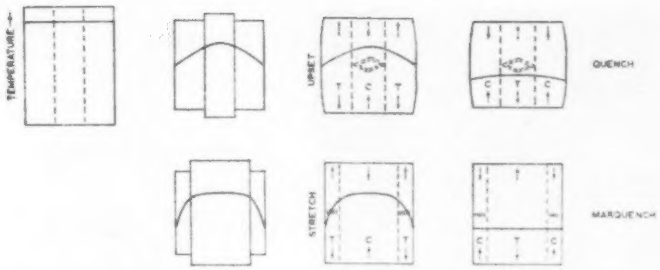
At a later stage, as the furnace temperature is approached, the temperature distribution levels out and the core will tend to expand. As it expands against the shortened surface layers, its growth is restricted and the core is now in compression, the centre in tension; by this time, however, the temperature throughout the block is high enough for all the stresses to relax elastically, without plastic yielding. In practice, there is a tendency for the expansion of a core to proceed laterally, so that the block bulges in the middle.

Upsetting on heating occurs when the stresses are high enough to produce plastic yielding and can be overcome by reducing the temperature gradient, particularly at fairly low temperatures. Slower heating can be achieved in practice by charging into a cold furnace and heating the component with the furnace, or by operating with two furnaces: one heats the component to an intermediate temperature, in practice just below A_1, the other is at the final hardening temperature. The component is heated in the low temperature furnace until the temperature is uniform and is then transferred to the high temperature furnace as quickly as possible.

During *quenching*, distortion occurs as a result of



6 *Effect of thermal stresses*



7 *Effect of cooling stresses with different temperature gradients*

thermal and of transformation stresses. In general, thermal stresses again have an upsetting effect. This is shown in the lower part of fig. 6. The surface layers shrink rapidly as the temperature drops while the core remains hot and correspondingly weak. The outside is in tension, the centre is in compression, and the centre is more likely to yield than the outside. Thus the core yields in compression and the block is 'upset.' Fig. 6 shows that a rectangular cross-section undergoes this hot upsetting action on both heating and cooling cycles; the effects are additive and the upsetting effect can be quite considerable. The figure also shows that, depending on which way you look at it, the upsetting effect can shorten a bar and make it bulge in the middle or it can shrink a disc and make its faces bulge.

In the heating cycle the thermal stresses can only have the upsetting effect just described. In the cooling cycle, however, it is possible that thermal stresses may stretch the block.

In fig. 7 we start with a block at a uniformly high temperature, at the point where it is removed from the hardening furnace; there is no distortion or internal stress. The upper part shows what happens on normal quenching and runs quickly through the upsetting mechanism again. The surface shrinks and upsets the weaker core, which yields plastically in compression. On further cooling the temperature becomes more uniform again, the compressed core tends to contract to a shorter length than the surface layers and thus imposes elastic compression on them, while the core itself is in tension.

It is possible, however, to visualize circumstances where the temperature distribution is rather like that in the lower part of fig. 7, with a very thin surface layer cooling very much faster than the rest and shrinking severely, while the hot core occupies the bulk of the cross-section. This will occur in the case of a heavy component of low thermal diffusivity quenched into a bath having a high rate of heat extraction, so that the surface layers reach the temperature of the quenching bath almost instantaneously. In practice, this corresponds to the marquenching or austempering of a heavy component in a lead bath or perhaps a salt bath.

Under these conditions, a thin surface layer shrinks considerably and is restrained by a large section; severe tension is set up in the surface and is balanced by a much lower compressive stress distributed over a lot more material. Thus, although the surface layer has a higher elastic limit than the core, the stress is so much greater that it is the surface that yields in tension. When the temperature has evened out, the 'natural' length of the surface is greater than that of the core and the total contraction of the block is less than it would have been if the surface layers had not yielded in tension. Thus, the block has been effectively stretched in the cooling cycle, although the amount is much less than the upsetting that occurs when the core yields in compression. Moreover, this stretching counteracts any upsetting that may have occurred in heating, so that it can be concluded that upsetting occurs more frequently and produces sharper effects than stretching.

The overall effect of thermal stresses in hardening is generally to upset the block, to shorten the largest dimension and bulge the smaller ones, that is to approach more closely to a sphere. Residual stretching may occur in isolated cases where heating has been slow enough to avoid plastic yielding while quenching is so severe that the temperature distribution corresponds to the lower one in fig. 7.

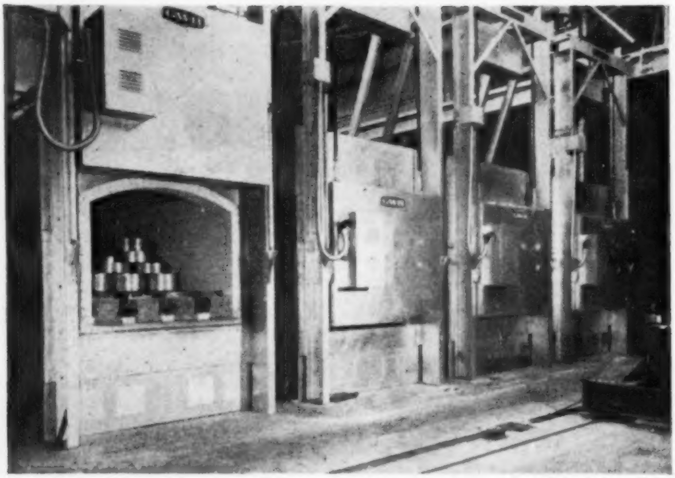
to be continued

S.I.M.A. satisfied with Moscow exhibition

The Council of the Scientific Instrument Manufacturers' Association states that its 19 members who took part in the combined stand at the recent British Industries Fair at Moscow are very well pleased with the results.

Firm contracts have been signed for 75% of the quarter of a million pounds' worth of their exhibits. Preliminary contracts for a considerable additional quantity of equipment to be exported immediately or in the near future have also been placed.

Although the Russian trading organizations were very busy, hard pressed, and drove hard bargains, they were also most co-operative and displayed a friendly spirit which was much appreciated by the S.I.M.A. members.



Annealing brass strip

The coils are heated to a temperature of 500–600°C.

FOUR NEW HEAT-TREATMENT FURNACES have been installed by Earle, Bourne & Company Ltd., tube manufacturers and suppliers of rolled metals. Designed and built by G.W.B. Furnaces Ltd., Dudley, the four electric batch furnaces will be used for the annealing of brass strip. The complete installation comprises not only the furnaces but also a heavy-duty steelworks-type turntable charging machine of Gibbons-van-Marle design and five loading tables.

Part of the Delta Metal Company, Earle, Bourne & Company Ltd. was formed in 1875 to produce brass strip and brass and copper tubes. In recent years much new equipment has been installed as part of the company's development project. Earle, Bourne cast their own metal and the billets are then rolled through Robertson strip rolling mills into a wide variety of strip widths and gauges. Intermediate and final annealing of this strip is carried out in the G.W.B. furnaces. The coils are heated to a temperature usually in the range of 500 to 600°C., withdrawn from the furnaces by the Gibbons-van-Marle charging machine and allowed to cool in room temperature. The company hopes to install a cooling tank in the near future so that the coils can be quenched immediately after leaving the furnaces.

Furnace details

The heating chambers are 20 ft. long × 5 ft. wide × 3 ft. 6 in. high to crown of door opening. Each furnace is rated at 342 kW. in three zones and is designed for operating up to a maximum temperature of 750°C. Two of the furnaces are equipped with reduced rating input control, so that they may operate, with very close temperature uniformity, at lower temperatures for charges requiring stress relieving.

The hearth incorporates three grooves to accommodate the arms of the charging machine, the piers being formed in single-piece, specially-moulded firebrick blocks. These piers are topped with heavy cast 24/12 nickel-chromium alloy heat-resisting steel plates, as are the wells of each groove which guide the chargers arm rollers. Arranged in sinuous form and fitted under the arched roof and in the hearth of the heating chamber, the heating elements are made from 80/20 nickel-chromium strip. Door elements are in the form of nickel-chromium wire coils and supported upon refractories incorporated in the door lining brickwork.

Each furnace is fitted with a counterbalanced door framed with mild steel and refractory faced. The drive for the door lift is obtained from an electric drive unit consisting of a motor transmitting through the necessary reduction gear box and spur wheel drive on to a main shaft, the latter being fitted with sprockets and robust chains attached by lugs to the door.

Each furnace's electrical equipment comprises a switchgear cubicle working in conjunction with an Ellison oil-immersed circuit breaker, and the temperature control is from three Electroflo indicating controllers and an Electroflo three-point recorder.

At the present time the G.W.B. furnaces are working 24 hours a day. Before they were installed Earle, Bourne sent out to other companies the greater majority of their annealing work, but now they have a complete, up-to-date and well-organized production line which will undoubtedly step up the company's output of brass strip.

Heat treating in the fluid-bed furnace

The fluid-bed furnace is rapidly achieving production status at Boeing Airplane Co. Among other successful applications, it has been used in austenitizing intricate parts of alloy steel and for removing residual stresses from aluminium parts. An account appeared in Metal Progress, *April*, 1961, *by Charles Bennett and Charles Jung, manufacturing development engineers, Aero-Space Division, Boeing Airplane Co., Seattle, Washington, on which the following description is based*

THE FLUID-BED FURNACE OFFERS close temperature control, rapid uniform heating and cooling, and temperature ranges needed to handle the heat-treating problems which have been incurred by the advent of such superalloys and refractory metals as René 41, Inconel 'X,' molybdenum and columbium. Furthermore, this new heating technique is now achieving production status in the processing of conventional steels and aluminium alloys.

During the course of its development, several simple fluid-bed systems for heat treating and quenching were built, the main effort being dictated by the need for immediate, practical solutions to specific problems in heat treating new metals. This article discusses some of the details of fluid beds and practical applications of the technique.

The general principle of fluid beds is well known. Adaptation of the method to production heat treating has several fundamental advantages, one of which is uniformity of temperature. This is achieved by the turbulent action in the bed which allows the small particles of sand (they act as heat reservoirs and carriers) to absorb heat from a localized heat source, and release it uniformly and rapidly throughout the bed. Because of the turbulence, the temperature can be maintained at a remarkably constant value. Tests have shown that such a bed, when stabilized at a given temperature, was uniform throughout its volume within approximately $\pm 1^{\circ}$C. from –46 to 1,090°C.

From the standpoint of aircraft production, fluid beds are relatively economical, being simple to erect and operate. Beds may be constructed in production shops using standard equipment and materials, and, being portable, can be easily moved wherever they are needed. For operation, attachments are made to a source of fuel, standard temperature sensing and recording equipment, and cylinders of compressed gas (or a blower) for the fluidizing gas. Since fluid beds do not require hearths, as do air furnaces, size is generally dictated by the work zone required to handle the largest workpiece. In fact, fluid-bed furnaces may be constructed to any size, large or small, and they can also be built shallow or relatively deep to fit specific shop areas.

Methods of heating

The bed can be heated in many ways; electricity, gas and oil are all usable. Induction heat may be used, or radiant heat may be introduced at the top of the bed. Gas may be burned directly in the bed. If oil is used, heat can be transmitted to the bed from a tube inserted in the bed or by impinging the flame against heat-conducting walls of the fluid-bed container.

As another advantage, specific atmospheres can be provided by simply changing the composition of the fluidizing gas. Various compositions and mixtures of refractory particles allow the selection of a fluidizing medium compatible with nearly any heat-treatment cycle and temperature requirement. In quenching, parts may be rapidly cooled through the critical temperature range; temperature drop is not retarded by a vapour phase, a feature of most liquid quenches.

In addition to being rapid and precise, temperature control is relatively simple. Temperatures can be reduced by turning off the heat source and allowing the fluidizing gas to quench the bed. An increase in temperature involves only a simple adjustment of control to introduce enough heat to bring the bed to temperature.

Fluidized beds offer a fail-safe feature that protects metal parts under heat treatment in the event that either the heat source or gas blowing equipment fail. In these eventualities, the bed either does not heat or does not fluidize. If heat fails, the bed starts to cool slowly, and if fluidizing equipment fails, the particle mass settles around the immersed part. Neither is a major problem. To place the bed in an inactive state, heat and fluidizing gas are turned off. Since the bed does not freeze up, the refractory lining and fluidizing particles cool slowly, unchanged.

The fluid beds built at Boeing range in size from small laboratory units to a prototype production model. Experimental work has, since the beginning, been coupled with production heat-treatment problems.

In one production example, a problem exists in the hot straightening of machined and heat-treated forgings from which warp has to be re-

moved at not over 180°C. Air furnaces take too long to heat the parts. A hot oil bath is used, but the problems of fire hazard, removal of hot oil from parts and oil splatter are present. A prototype fluidized bed is now being used in the shop concerned to gather research data in connection with this problem.

Austempering alloy steel

Another production application involved the successful austempering of a 36-in.-long ring segment of an alloy-steel part (A.I.S.I. 4330-M). Because of the complicated shape, conventional quenching and tempering resulted in excessive warpage in the close-tolerance parts. With fluid beds being used for austempering, however, warpage in 65% of the segment was less than 0·001 in. and maximum warpage was less than 0·005 in.

Austempering by fluid bed differed slightly from conventional austempering. First, the part was austenitized at 870°C. in a conventional air furnace. It was then quenched in a fluid bed held at 320°C. When the part and bed reached a steady-state condition, the heat source was turned off. With the halting of fluidization, the sand settled around the part to insulate it. After holding for 2 h., the part was removed. In this instance, the insulating property of the bed maintained the part at 320°C.—an operating economy not obtainable in other types of furnaces.

Inverse quenching to remove stress

A current research problem involves the use of a fluid bed as a rapid-heat facility in inverse quenching studies. Investigation into the novel process with a fluid bed has shown that not only aluminium alloys but René 41 and titanium can be thermally shocked by the rapid heat transfer produced when a cold part is put into a hot bed. The residual stresses which are thus removed result in the reduction or elimination of warpage during machining; shelf life is also better.

One part thus treated was an A-360 casting that required machining to close tolerances. It had previously been machined from solid bar stock, and considerable savings were anticipated from use of a newly designed die casting. After several lots were finish machined, however, all of them warped out of tolerance after one day on the shelf and were rejected. As-cast parts were then inverse quenched in a fluid bed from room temperature to 180°C. After machining and shelf-life tests, all passed inspection. In stress removal from parts made of alloys such as René 41 and titanium, the parts were inverse quenched to the highest temperature not detrimental to the mechanical properties. These tests also proved that inverse-quenched parts warped less after machining than did unprocessed parts.

A portable fluid bed has also taken a role in the development of explosive forming at elevated temperatures. In this application, hot sand at 760°C. is used to heat the parts. The bed is housed in a temporary structure and is gas heated; a blast of air from the compressor then fluidizes the bed.

Fluid beds are safer

In the field of safety engineering, the use of fluid beds for heat treating deserves mention. They reduce the hazard from water that is spilled into the fluidizing medium. Instead of a violent reaction, water turns to steam which escapes with the fluidizing gas. Also, there is no splash hazard from inserting or removing parts, and the beds are fail-safe. Surface water and moisture on parts is likewise not hazardous (unless, of course, moisture is locked inside a part as might occur in a porous casting).

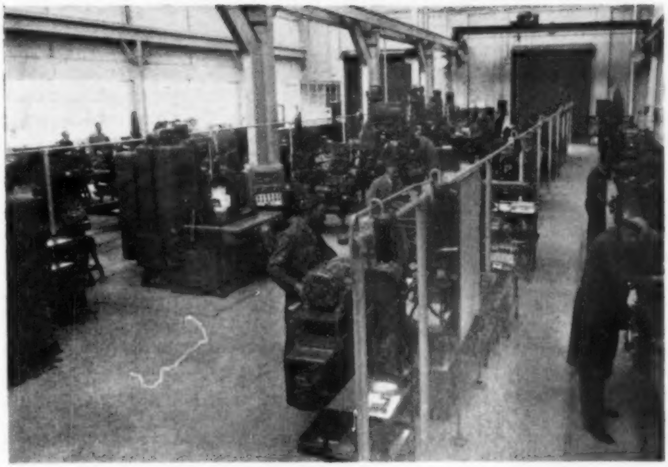
At Boeing, those who have participated in the development of fluid-bed furnaces are enthusiastic about the possibilities of the new heat-treating technique. It provides a new and refreshing approach to the solution of some traditional heat-treating problems as well as many newer problems. To those who have worked with it, the fluid bed is a dynamic thing with a character all its own. Since it often seems to defy the rules of logic and common sense, additional research and development work is necessary to assure optimum design and operation. One of the oft-quoted expressions among Boeing heat-treatment specialists who have designed, built and used the fluid-bed furnaces is, ' Give it lots of loving care—and when it's working, don't change a thing.'

Advantages of electro-heat in industry

' ELECTRICITY BOARDS have an obligation to see that electricity makes the maximum contribution to productivity in industry. The development of industrial load, apart from being important to the supply industry, might be regarded as a social obligation. We can assist in increasing productivity by making known to industrialists the advantages of electrical production methods and by introducing modern techniques into their works.'

This was stated by Mr. A. Ellison, A.M.I.E.E., commercial officer of the North Eastern Electricity Board, Thornaby-on-Tees, in the course of a paper on the small industrial consumer, given to the Electrical Development Association's Sales Conference at Harrogate.

In general, said Mr. Ellison, processes benefited from the use of electro-heat where (1) high temperatures are involved; (2) the value of the product is high in relation to the heating costs; (3) high accuracy of time and temperature control is necessary; (4) absolute cleanliness is required; (5) the heating process is an isolated one in a manufacturing cycle, *i.e.* where the other operations do not require heat; and (6) manufacturing costs can be reduced by carrying out the heating processes in the line of production.



Research in the machine-tool industry

View of section of the new Herbert Applied Research Department at Coventry

IT IS NATURAL that only the more spectacular achievements of science and technology should command the attention of the public. Relatively, therefore, it may appear that little research is conducted by less newsworthy industries which, nevertheless, have a more direct impact upon the standard of living of the community at large. Furthermore, owing to the demands of commercial secrecy, even the technician applying the results of industrial development to his own job may sometimes feel that such research is spasmodic rather than continuous.

This impression would appear to have been confirmed, as far as the British machine-tool industry is concerned, by the inordinate amount of criticism to which it has been recently subjected. A major source of such criticism was the still unpublished report by Professor Seymour Melman to the European Productivity Agency of the Organization for European Economic Co-operation (OEEC); admittedly, this was written within the context of the whole Western European machine-tool industry. Subsequently, the Mitchell Committee, set up by the Machine Tool Advisory Council of the Board of Trade to consider the Melman report, found that it could not agree with many of the Melman conclusions, but it did report that it considered the research programme of the British machine-tool industry as a whole to be inadequate. Nevertheless, the Mitchell Committee excluded certain unnamed major companies within the industry from the main body of this criticism.

In this atmosphere of misgivings concerning the ability of the British machine-tool industry to meet the needs of future industrial expansion at home and the challenge of foreign competition abroad, the recent opening of new premises for applied research at the head works of Alfred Herbert Ltd., Coventry, is an appropriate opportunity to review the research and development effort of one of the leading members of the industry.

Aims of research and development

The machine tool is not wholly an end-product in itself, but is a means to an end. Research and development in the machine-tool industry is concerned, therefore, with the economic production of materials and components in the engineering industry at large. A programme aimed at the improvement in manufacturing techniques falls into two groups: (1) Research into fundamental problems confronting the machine-tool maker, such as accuracy (both initial and maintained), the causes and cure of vibration and noise, the reduction of friction, the effects of thermal expansion, and the conflict between the cutting materials and the materials cut; and (2) development in the more immediate fields of metrology and production, which include work-holding and work-loading devices, pre-set and quick-change tooling, cycle control and positioning devices, the reduction of setting and idle times, and a study of general ergonomics to ensure that the natural human limitations do not limit the performance of the machine.

In view of the diversification of output from the metal-working industry, the task of anticipating

its future needs is complicated. Demands for machines for mass, flow-line, batch and unit production must be combined with the need for accepting a seemingly unlimited variety of components, materials operations, and degrees of accuracy. The complex combinations of these factors are not necessarily reduced when the machine is designed for smaller production runs, which must be sufficiently versatile to ensure that it is fully utilized throughout every working shift.

How, then, does the machine-tool manufacturer plan a research and development programme to ensure that new machines and methods are available when the need for them arises? Being concerned with one type of manufacture in his own works, he cannot employ his own experiences as a criterion of the developing needs of industries engaged in other activities. There are, however, three approaches: (1) Continuously to assess the components manufactured in customer factories, and by intelligent extrapolation predict the needs for the future; (2) to develop the existing functions of the machine, working on the natural assumption that industry requires lower operating times, reduced setting and tooling costs, and greater machining precision; and (3) to keep in close association with such outside bodies as research organizations, cutting material manufacturers, and manufacturers developing new materials to be cut.

The information for assessing the components being manufactured in the engineering industry is easily obtained. Most large machine-tool manufacturers employ staffs of qualified production and machine-tool engineers to which existing and prospective customers submit their production problems, and Alfred Herbert Ltd. is one of the pioneers of this type of service. Enquiries for machine tools, averaging 18,000 per year, come from all parts of the world. In response to enquiries the Herbert sales engineering staff currently deal with an average of 280 engineering studies per month, ranging from simple tool layouts to complete plants.

Considering the second approach to research, namely, the development of existing machine functions, it will be noticed that no mention was made of the introduction of new functions. Since the late Sir Alfred Herbert founded his company 70 years ago, development of machine tools has been progressive, but there has been no startling change in their fundamental concept. At that time machine tools were crude, if compared with modern products, but their *modes* of operation had by then been fully exploited by the pioneers of the previous century. This is not surprising if it is appreciated that a machine tool is capable of operating in only three planes, and with a rotary or linear motion. Even a machine tool which combines the functions of all types of machines, although complex, could not be developed to function in another spatial dimension. However, a dimension that could be exploited was that of 'time,' and developments in this direction have been vigorously pursued throughout the years, and much further work can be done, and is still being done, to this end.

Despite these geometrical limitations, it is not conceded that they have proved an embarrassment to the development engineer and designer. Intelligent application of applied research to the known functions of machine tools have produced results which have had profound effects upon production techniques. Considerable ingenuity has been shown in combining and accelerating the machine functions to produce components of increasing complexity of shape in decreased floor-to-floor times.

The latest advances in tape and punched-card programme and positioning control of machine tools have had a considerable effect not only upon machining and setting-up times, but also upon the quality of the finished component, since the consistency of slide movements, which cannot be matched by even the most skilled operator, have considerably reduced tool wear and consequently increased production between tool regrinding. Furthermore, these electronic devices, when used for positioning control of machines, have far-reaching ramifications into departments outside the production machine shops. Their introduction is gradually eliminating the need for large staffs of experienced jig-and-tool draughtsmen whose skills can be more usefully employed on design and development as their function is transferred to the production of punched-tape and other services.

Applied research facilities

The first laboratory in the Herbert works was established as early as 1910. With the passage of time the range of research has been enormously widened by the development of new metals and new techniques, and additions to the specialist personnel engaged have been consistently needed to cover the growing fields of investigation and proof.

In later years, with the trend towards more intensive specialization, it has become necessary to promote greater liaison between the specialists and to integrate and extend the mechanical and electrical development work of the whole company. As a first step a new design wing was built and, in addition, an adjacent plot of land was earmarked for the erection of a building to house the Applied Research Department. The opening of these premises last month marks the fulfilment of these plans.

Metallurgical laboratory

Although much of the development work at

Alfred Herbert is conducted in the Applied Research Department, a major contribution is made by several other departments working in close collaboration.

One of the oldest-established of these is the Metallurgical Laboratory, which deals with the development and testing of materials and material processes. It has for many years been an A.I.D. approved laboratory whose analytical and physical testing services are widely used by local manufacturers.

Part of the function of the department is the testing of all materials delivered to the works to ensure that they are to specification. Furthermore, a strict control is kept on the processes in the foundries and hardening shops—temperatures are checked and analyses of mixes are made from samples drawn from each charge in the furnaces. These are routine quality control checks to ensure that the materials used are the most suitable for their particular purpose.

As the result of the experience gained, advice is also given to the production departments on the most efficient processes, and suggestions can be made for changes of specification when dictated by the process or by the modified use of the finally finished component.

A description of the contribution made by the firm to metallurgical research in the machine-tool industry must include the 'Flamard' treatment introduced in 1932. At that time flame-hardening of steels was not new, but it had not been applied to cast iron because of many technical difficulties involved. The advantages of applying this process to the production of machine bedways was, however, recognized and, despite the difficulties, a process was pioneered which considerably increased the hardness of these members without impairing the natural self-lubricating properties of cast iron.

New materials are continually being tested in these laboratories as soon as they are introduced. Constant perusal of technical papers and industrial journals and close collaboration with other laboratories ensures that samples are obtained for physical testing, chemical analysis, and assessment of machinability before enquiries are received from customers. A typical example, now commanding the attention of the laboratories, arose when a discrepancy was observed between the machining times for cast iron in the U.K. and in another country. Since the machines, tools and machining techniques used are similar in both countries, the difference can only exist in the iron itself. Whether this is due to differences in composition, in casting technique or in the basic quality of the ore available will emerge when the problem has been comprehensively investigated.

A development of the Metallurgical Laboratory which has also had a considerable influence upon production in the hardening shops is the design of a Ferroscope. This instrument can indicate variations of size, hardness, chemical composition and phase constitution of components made of iron or steel, by virtue of the effect of these factors upon the magnetic properties of ferrous materials. The concept of the Ferroscope is not new and instruments were previously in existence which relied upon the observation of changes in a trace on a cathode-ray tube.

The Herbert Ferroscope, however, was designed to indicate, to a high grade of sensitivity, the variations from a null reading obtained by the simultaneous examination of two samples and, it is believed, was the first instrument of this kind to be designed.

Tungsten-carbide

Although tungsten-carbide was first introduced in the early 1930's, and it was realized that its hard diamond-like properties could be utilized for metal cutting, its general adoption for this purpose was only slowly achieved over a number of years. This was due to a number of unavoidable and interdependent factors. Firstly, the first carbides were not entirely successful; they were hard but brittle, which contributed to tool breakages and rapid tool wear. Secondly, their successful use required a revolutionary change in machining techniques which necessitated a lengthy study of the fundamentals of metal removal before the new techniques could be evolved. Such a study had not hitherto been necessary. Like those of many other industries that had developed from traditional crafts, machining technique had been successfully evolved through long experience at a time when development was largely empirical and modern research tools were not available for an intensive study of the underlying theoretical concepts. Lastly, the products of most machine-tool manufacturers were unable to withstand the stresses imposed by the vigorous machining requirements of these new tools.

It is believed that the first sintered tungsten-carbide made in this country on a scale sufficient to enable its economic exploitation for tools was produced by the B.T.-H. Co. (now the A.E.I.) as a result of their researches into tungsten compounds in connection with tungsten filaments for lamps. This material was tentatively offered to Alfred Herbert Ltd., who, recognizing its possibilities, promptly signed an agreement for the sole distribution rights.

Initially the entire output was used in the Herbert machine shops for machining cast iron, for which purpose it was very successful. As production increased, small quantities of carbide-tipped tools, known as Ardoloy, were also sold, and an Ardoloy

Research Department was founded to investigate the application of Ardoloy to metal-working production. The metallurgical research was, however, left in the hands of the B.T.-H. Research Department and, by close collaboration between the two departments, there have been parallel developments in carbide composition and its application. This arrangement has been eminently successful, for today adequate facilities for research into this single aspect of tool development are provided by the large A.E.I. organization, who also makes use of them for general research into powder metallurgy.

For steels it was soon found that the tool tips were subjected to breaking and cratering and the B.T.-H. laboratories were requested to develop tougher carbides whilst still retaining their properties of hardness. At the same time the Ardoloy Research Department was analysing the cutting forces on the tool tip in order to permit cutting under compression rather than tension. This was achieved by grinding the tool with a negative rake, a procedure which met with considerable resistance at the time from traditionalists in industry. Further research showed that a negative rake required deeper cuts and faster cutting speeds, and these, in turn, produced finer component finishes, owing to the 'plasticizing' of the metal under the tool tip.

Complete machining techniques have been developed for all types of materials on lathes, milling machines and planing machines and development work still continues.

Metrology

Metrology has been developed as a science only in the last 30 years or so; its development gained impetus through the ever-increasing accuracy required in industry. The instruments originally designed for the toolroom have been developed for mass inspection in the production shops, and automatic inspection devices directly controlling the machine functions have made a considerable contribution to the reduction of overall production times and the elevation of machining accuracy.

Alfred Herbert Ltd. had not been greatly engaged in the actual production of measuring and inspection equipment until the Sigma Instrument Co. Ltd. joined the Herbert Group 12 years ago. Nevertheless, such instruments had been sold through the Herbert Sales Organization and their design has been considerably influenced by Herbert experience of the requirements of industry and by the developing study of metrology in the standards room.

Future trends

Mass-quantity production methods are employed by but a few specialized industries, such as the domestic appliance and car industries, who serve the needs of an assured mass market. But the overwhelming proportion of production units in this country and overseas can collectively supply the consumer with a wide freedom of choice, whilst maintaining maximum flexibility compatible with economic stability, by flow-line and batch production methods. This is also true of the Soviet Union having a large domestic market and bureaucratic control of product variety. No changes can be foreseen in this pattern of industrial requirement either in the near or distant future.

Heat transfer between metals in contact

Basic information has been obtained on some of the factors which affect the transfer of heat between two machined metal surfaces. The transfer of heat between solid surfaces is widespread, for example, between fuel rods and cans which are in static contact in a nuclear reactor, and between the riveted components of an aircraft subjected to aerodynamic heating.

Measurements of the heat transfer between machined metal contacts have been made with brass and aluminium surfaces of four different values of roughness in contact with steel and brass surfaces of two different roughnesses. Contact pressure was varied between 14 and 11 400 lb./sq. in.

It was found that most of the heat was transferred by surface contact and conduction through the intervening fluid. The fluid conductance was found, as expected, to be directly proportional to the thermal conductivity of the fluid and inversely proportional to an 'effective fluid film thickness'; the way in which the effective fluid film thickness depended on surface roughness was determined.

The conductance through surface contact was dependent on applied pressure, surface hardness, surface finish, and the thermal conductivities of the solids; the relation between these factors was obtained. A theoretical expression for the surface contact conductance has been developed, based on the resistance to heat flow associated with a constriction. It gave good agreement with the experimental results when the variation of metal hardness with load in the micro-hardness region was taken into account.

This work was carried out for the National Engineering Laboratory at the Imperial College of Science and Technology, University of London.

Further information is given in: *NEL Report Heat* 182 ('Thermal and electrical conductance of machined metal contacts,' by L. C. Laming) available from the laboratory.

Noise in factories

The noise to which a worker is exposed can readily be measured, in terms of frequency and intensity, by the use of a sound-level meter. Moreover, recent work has led to the drawing up of charts of allowable exposure. By comparing a measured frequency-intensity curve with such a chart it is possible to specify the maximum exposure (in hours per week) which a worker may be expected to tolerate without impairment of his hearing.

Typical results obtained in this way are quoted as follows: grinding wheel 1 h.; power press 5 h.; tumbling barrel 4 h.; air screwdriver 6 h.; woodsaw 4 h.; roller conveyor 6 h.; air compressor 8 h.

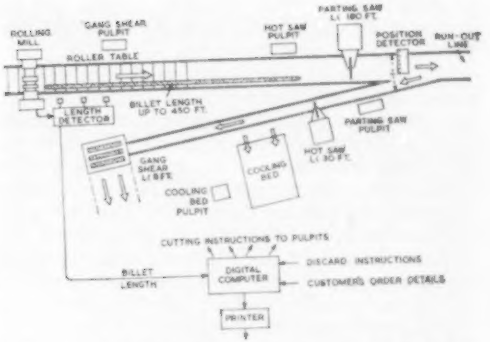
Noise can be reduced by the provision of anti-vibration mounts or soundproof enclosures for equipment, or by equipping operators with ear muff or plugs. Regular audiometer checks of workers exposed to noise should also be made.

On-line computer control of steel billet cutting

First digital computer for the on-line control of an industrial process in the UK is now in operation at the Stocksbridge works of Samuel Fox & Co. Ltd. This achievement is the result of a long period of collaboration between Samuel Fox and Elliott-Systems engineers, involving design studies which forecast considerable savings from reduction of waste material. Satisfactory operation commenced in February and, although sufficient evidence is not yet available fully to substantiate that the predicted savings are being realized, Samuel Fox engineers do not doubt that the expected saving will be achieved.

The company rolls billets of high-quality steel to lengths of up to 450 ft. before cutting them to customers' requirements. Since the steel is largely to special order, the billets must be cut to produce minimum wastage within the limits of the customers' specification and the length finally rolled. The problem is complicated by the layout of the mill, which necessitates the use of cutting at two or three points.

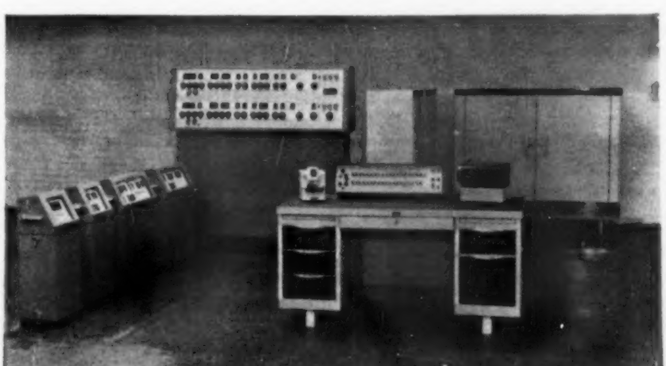
The complete problem falls into four parts: first, the measurement of billet length; second, the calculation of optimum cutting points; third, the transmission and display of this information to operators; and, finally, the recording of data for office purposes. There are many aspects which invite and challenge the use of a digital computing system. The computation has to be fast enough not to hold up the billets on the track, a self-calibrating length measurement system is required and, since a number of billets can be on the track at the same time, considerable capacity for the storage of information is required.



1 *Diagram of the Elliott-Automation computer control system for a billet cut-up line at the steelworks of Samuel Fox*

The joint study of this situation by Samuel Fox & Co. and E-A Automation Systems Ltd. (a member of the Elliott-Automation group) showed that there was ample economic justification for a computer to optimize the cutting at this point and an order for such a system was therefore placed. The system has been designed to include the Panellit 609 information system which incorporates the Elliott 803 general-purpose computer.

The measurement of length is obtained by a self-calibrating pulse-counting system which compensates for the wear on the mill rolls. The presence or absence of the billet is detected by lead sulphide detectors which have the correct spectral response to detect even the billets which have been delayed at an earlier stage of rolling and have, therefore, cooled



2 *Equipment for the automatic computer control system for the steel billet cut-up line at Samuel Fox. The display pulpits (on the left) tell operators at the saws the lengths to which billets are to be cut. Next to them is the console on which order-book information is set. Other units in the background house the computer and associated equipment. In the foreground is the control console*

to about 450°C. This detecting system and its enclosure was specially designed by E-A Automation Systems for this application.

The customers' order is set up on a panel controlled by the mill foreman. This method of input was chosen in order to maintain the personal responsibility of the foreman for the running of the mill. The order may specify for the final billet a fixed length, a limited continuous range, or a range consisting of a series of steps. The computer must calculate the optimum cutting points to satisfy the customer's requirements within the mill operating conditions and also make allowance for the required test-pieces as well as making statistical allowances for the variability of the stops at each saw and shear. This calculation takes less than a second and the information for the operators to use in setting their shears is therefore available within 1 sec. of the billet leaving the final mill. Most of this information is, however, normally stored in the computer until it is called for by the operator.

Each operator has a display panel on which information relating to the billet that he is about to cut up is displayed following the operation of a demand button, and checks are provided in the computer to ensure that the billet the operator is cutting corresponds with the one displayed on his panel. This is only one of a comprehensive series of checks in the computer programme that ensure that any abnormalities in the operation of the system are rapidly detected and identified.

One of the advantages of the stored programme of the 803 computer is that changes in mill or system operation can be incorporated with very little trouble at any stage of the design or after the system has been installed. The manual operations retained in this system can, of course, be replaced by automatic links when the system has been proved in operation should this appear to give further gains.

Vacuum casting of steel at Steel, Peech & Tozer

AFTER TWO YEARS of trials on the vacuum casting of steel, involving the production of several thousand ingot tons, the Steel, Peech and Tozer branch of the United Steel Companies Ltd. are believed to be the first company in this country to make steel produced by this method commercially available.

The object of vacuum casting—or degassing—is primarily to remove hydrogen from the steel. This can also be achieved by suitable heat treatment but, in the case of comparatively large section sizes, such as medium and heavy forgings, the heat treatment necessary to remove hydrogen by diffusion may take several hundred hours to complete. By casting the steel in a vacuum, however, hydrogen removal can be accomplished in a matter of minutes.

All hydrogen levels after vacuum casting are sufficiently low to eliminate completely the need for such normal hydrogen precautions as the slow cooling of rolled blooms or the extended heat treatment of large forgings. The oxygen content is appreciably lower than on air-cast samples, although the nitrogen content of the steel is not greatly affected by vacuum casting, only about 15% being removed on average. Carbon content tends to decrease by one or two points and sulphur is lowered by an average of 0·001–0·002%. Alloying elements remain unchanged, and this includes manganese.

Mechanical tests have shown that the properties throughout large forgings made from vacuum-cast steel are more regular and that the ductility, in particular, is good. Transverse properties are also improved. Impact properties are good and no significant difference in transition temperature has been found.

The equipment employed for vacuum casting at Steel, Peech and Tozer consists essentially of a cylindrical casing of ½-in.-thick welded-steel plates. This 11-ft.-dia. chamber is fitted with a removable lid having water-cooled flanges, the vacuum seal being effected by a neoprene rubber gasket in the flange.

The sequence of operations begins with the positioning of ingot moulds in the vacuum chamber. The lid is then secured and the chamber is evacuated by steam ejector pumps to 0·5 mm. of mercury or 1/1,500 of an atmosphere. A ladle of molten steel is brought by overhead crane to the vacuum chamber and steel is teemed through a small opening in the lid at a controlled rate.

As the steel enters the chamber, it is broken up into a fine spray due to the explosive release of gases, caused by the vacuum. It is this characteristic which enables very rapid degasification to take place, the process continuing at a slower rate when the steel is in the ingot mould. On completion of teeming, the vacuum is gradually released and the ingot allowed to cool in the normal way.

At the present time, steel for vacuum casting is being melted in a 7-ton electric arc furnace at Steel, Peech and Tozer. As an integral part of the company's £10-million scheme to replace all its open-hearth furnaces with six 110-ton-capacity electric-arc furnaces, however, it is planned to incorporate facilities which will permit the vacuum casting of the very much larger tonnages of steel produced in these furnaces.

Aluminium lighting columns

AMONGST current applications of aluminium, that for lighting columns is probably unique in the manner in which full advantage is taken of certain properties of the metal for static applications. Because aluminium possesses the required properties, it is fast proving more than competitive with alternative materials. The account which follows concerns the present production of Metal Developments (1960) Ltd., Birmingham, 1, and on pioneer work carried out by this company more than nine years ago.

At that time, the organization erected a tubular aluminium alloy (NS4) lighting column with a smooth metallic finish in the forecourt of its works at Bilston, Staffs. The column, which was formed from sheet and welded by the oxy-acetylene process, is still in position and in perfect condition. It has withstood nine years' exposure to an agressive industrial atmosphere and is set direct in red ash, itself highly aggressive but which has, however, caused no deterioration at all in the (non-bituminized) buried part of the column. It is interesting to note in the case of this particular column that the welding-line, apart from one or two localized spots of thin black staining, shows no sign of preferential weathering attack, either above or below ground. Nearby is a similar tubular column, similarly produced, but using argon-arc in place of oxy-acetylene. This column was erected at about the same time and is in perfect condition both above and below ground. It has weathered quite normally, shows no apparent pitting, and preserves a clean metallic appearance below the layer of soot and grime which normally covers it until it is washed free by rain.

From 1957, the company began manufacturing lighting columns on a definite production basis. The type made was Class B, measuring 16 ft. overall, with 14 ft. mounting height. Two patterns, both to designs accepted by the Council of Industrial Design, are made: the one, the 'Lucerna,' is of tapered tube of circular cross-section (8 in. o.d. at base; 2¾ in. o.d. at lantern end), the other, the 'Sheerline,' being of tapered hexagonal form (6¼ in. o.d. across flats at base; 2½ in. o.d. across flats at lantern end).

In both cases, the blank for the column is cut from 12-gauge NS4 sheet supplied by the British Aluminium Co. Ltd. Forming is carried out on machines designed especially for the purpose by the company's own engineers. Next, the seam is welded—using a Sigmette machine supplied by the British Oxygen Co. Ltd. A hole is now cut for the door and the door and lock are fitted, a backboard being mounted inside the column to take the choke and ancillary gear for the light. A base plate is next fitted, whilst at the lantern end of the column a ferrule-collar in 3-in.-o.d. aluminium alloy is slipped on and welded into place. For the 'Lucerna' a hammered silver-grey-painted finish is preferred, whilst the 'Sheerline' is regularly finished by anodizing.

Advantages

The most obvious benefit obtained by using aluminium alloy is ease and economy of handling. The weight of the Class B column in aluminium is about 35 lb., whilst corresponding concrete columns would weigh several hundredweight.

'Lucerna' aluminium column at Wolverhampton struck and holed near base by motor vehicle, but otherwise still in sound order

Unlike steel or iron, aluminium, even when exposed to aggressive industrial atmospheres, or to the salt spray of marine environments, needs no painting to protect it against corrosion or to guard against unsightly rusting; thus notable savings are effected in maintenance. It has been shown that in very hazardous situations, such as on piers run out to sea, aluminium lighting columns can withstand the influence of the salt-laden water with which they are sprayed. Steel and concrete columns deteriorate rapidly under these conditions.

More recently, a further advantage of the aluminium-alloy column has emerged. Should a vehicle strike and shatter a concrete column, the chances are that projected masses from the upper portion of the column will fall and cause injuries. This type of accident is effectually minimized by the use of lightweight aluminium columns which may 'fold up' or even break off short, but which will, in any case, do less damage as their mass is low. Moreover, if a vehicle should chance to collide with an aluminium lighting column, the nature of the metal is such that it will dent, in other words, plastic deformation will occur preferentially in the substance of the column and not in that of the car. In this way, energy is absorbed and the resulting deceleration of the moving vehicle will be proportionately less violent than that which occurs when impact takes place against a less-yielding material. Aluminium structures are notable for their ability to dissipate energy-of-collision in this way.

The fact that, in addition to its various merits set out above, the aluminium lighting column can be marketed at a price comparable with columns in other materials, taken in conjunction with lower installation and maintenance costs, makes it outstandingly competitive.

NEWS

Soviet Exhibition in London

The Soviet Exhibition in London, like the British Trade Fair held in Moscow recently, is being held under the joint sponsorship of the Association of British Chambers of Commerce and the Chamber of Commerce of the USSR.

The Soviet Exhibition in London is being organized by the Chamber of Commerce of the USSR in conjunction with Industrial and Trade Fairs Ltd. (London) and takes place at Earls Court from July 7–29.

The Chamber of Commerce of the USSR is a public organization, the chief aim of which is to foster existing business contacts and establish new ones with foreign firms and also to extend trade within the Soviet Union. It has very close relations with all trading and industrial associations of the Soviet Union.

All Soviet foreign trade associations and the Economic Councils have rendered effective assistance to the Chamber of Commerce in organizing the Soviet Exhibition in London. The USSR Academy of Sciences and a number of other organizations have taken an active part in preparing the exhibition. About 1,000 industrial enterprises of the Soviet Union contribute exhibits.

The USSR Ministry of Foreign Trade has lent full support in holding the exhibition. One of its high-ranking officials, Boris Gordeev, has consented to act as Director of the exhibition.

The Chamber of Commerce of the USSR, as a co-sponsor of the exhibition in London, will cover all expenses connected with its promotion.

Like the British Trade Fair in Moscow, the reciprocal Soviet Exhibition in London is a trade and industrial display. Its object, therefore, is to show export and import possibilities in the further expansion of Anglo-Soviet trade.

COURSES

College of Advanced Technology, Birmingham Department of Metallurgy

Two post-graduate courses are being arranged for the Autumn Term, 1961, as follows:

Practical implications of metal physics: a course of 10 lectures by leading authorities, on Tuesday evenings, commencing October 10, 1961.

Technology of non-ferrous secondary metals: a course of 10 lectures on Wednesday evenings, commencing October 11, 1961. Topics covered will include surveys of non-ferrous metals and alloys, sampling and sorting, melting and refining techniques and commercial practice.

Write to the Bursar, College of Advanced Technology, Gosta Green, Birmingham 4, for further particulars and application forms. Fee for each course £2 10s. 0d.

Borough Polytechnic, Division of Metal Science

Modern developments in non-destructive testing of metals: a course of six lectures, given by specialists from industry, on consecutive Wednesday evenings at 7 p.m., commencing October 4, 1961. Fee for the course 10s. 0d.

Refractories, their manufacture, properties and uses: a course of 10 lectures, given by L. R. Barrett, M.A., B.SC., M.S., A.R.I.C., M.INST.F., F.INST.CERAM., on consecutive Friday evenings at 7 p.m., commencing October 6, 1961. Fee for the course £1.

Recent advances in semi-conductor metallurgy: a course of six lectures, given by A. S. Abrahams, M.A.(CANTAB.), A.I.M., on consecutive Tuesday evenings at 7 p.m., commencing October 24, 1961. Fee for the course £1.

Schuler Presses Ltd.

L. Schuler A.G., Goeppingen, Wuertt, Germany, and Wickman Ltd., Coventry, announce the formation of a jointly-owned British company, Schuler Presses Ltd. The new company has been formed to establish the manufacture of certain Schuler presses in the U.K. and to provide a U.K.-based engineering and after-sales service to all Schuler press users.

Wickman Ltd. will act as exclusive sales representatives for the range of Schuler presses.

Lead Development Association

The new address of the Lead Development Association is 34 Berkeley Square, London, W.1 (GROsvenor 8422).

Ultrasonic testing of large steel forgings

Although ultrasonic examination by manual methods has been standard practice for some years at the Atlas Works of Thos. Firth & John Brown Ltd., recent trends in connection with the generation of electric power have increased its importance. Rotor forgings are larger, heavier and more highly stressed. It is important to ensure that no defect which could cause failure in service goes undetected. The increase in weight makes manual manipulation almost impossible.

Specially designed automatic rotating equipment has been installed in the heavy machine shops for ultrasonic examination of these forgings.

PEOPLE

THE NEW PRESIDENT of the Aluminium Development Association for 1961-62 is **Mr. G. W. Lacey,** C.B.E., B.SC., F.R.I.C., assistant managing director (overseas) of the British Aluminium Co. Ltd.

Mr. Gerald Lacey was with Lever Bros. Port Sunlight Ltd. from 1914 to 1928, except for war service 1915-19, and for the next nine years he was with the Birmingham Aluminium Casting (1903) Co. Ltd. In 1937 he began his long career with the British Aluminium Co. Ltd., interrupted, again for war service, in the second world war when he seconded to the Light Metals Control of the Ministry of Aircraft Production, as Controller of Light Metals. In 1945 he returned to the British Aluminium Co. Ltd. as a director. The honour of C.B.E. was conferred in 1946. Mr. Lacey served as a member of the Council of Industrial Design from 1947 to 1959.

The new president was a member of the executive committee of the Association from 1945-59 and served as its chairman for two years. Since 1959 he has been a member of the council of the A.D.A.

Garringtons Ltd., a member of the G.K.N. Group, have trained many outstanding apprentices and one of their employees, **Robert Morris,** who was the first 'Apprentice of the Year,' had the honour of speaking on behalf of the apprentices of Britain at the civic banquet given when H.R.H. the Duke of Edinburgh visited Birmingham last month during the Commonwealth Technical Training Week.

The 'Apprentice of the Year' award was inaugurated in 1958 by the British Junior Chambers of Commerce, when Robert Morris, then an engineering apprentice at Garringtons, was the winner. This award was in the form of a travelling scholarship, and he spent the next twelve months in Australia. During his visit he studied engineering technology whilst working with various companies in the Commonwealth.

Upon his return to Garringtons Ltd. at Bromsgrove, he continued his apprenticeship until September last, when he was appointed to the permanent staff, and now holds the position of assistant to the forge development engineer.

Mr. R. F. G. Lea, deputy chairman and joint managing director of CIBA (A.R.L.) Ltd., Duxford, Cambridge, has been appointed a director of CIBA Clayton Ltd., Manchester.

Mr. R. F. G. Lea

Mr. St. John de H. Elstub, C.B.E.

Mr. St. John de H. Elstub, C.B.E., has been appointed chairman of the Metals Division of Imperial Chemical Industries Ltd. in succession to Mr. M. J. S. Clapham, who has joined the company's main board as an overseas director.

Mr. Elstub, who is 45, was born at Heywood, Lancs. and educated at Rugby and Manchester University, where he took an honours degree in mechanical engineering. After three years as an engineer with I.C.I. Billingham Division, he joined the R.A.F. in 1939 and served for six years, first as an operational bomber pilot, later as a flying instructor and, for the last year, as an armament officer on technical intelligence and rocket design. After demobilization, he spent two years with the Ministry of Supply as chief engineer and deputy chief superintendent of the Rocket Propulsion Department at Westcott. In this capacity he was responsible for the design of the first British liquid-fuel rocket motor.

Mr. Elstub rejoined I.C.I. in 1947 as a deputy chief engineer of the Metals Division. He was appointed to the division board in 1951 as director in charge of metal production, but later in the same year was seconded as director in charge of Summerfield Research Station, the rocket research establishment managed by I.C.I. Metals Division for the Ministry of Aviation. He resumed full-time duties as metal production director of I.C.I. Metals Division in 1952, and was appointed joint managing director in 1957. He was awarded the C.B.E. in the 1954 New Year Honours for his contributions to rocket technology.

Mr. Elstub is chairman of Amal Ltd., an I.C.I. subsidiary, and a director of Yorkshire Imperial Metals Ltd., the tube producing company operated jointly by I.C.I. and Yorkshire Copper Works (Holdings) Ltd.

He is a member of the Institute of Metals and of the Council of the Institution of Mechanical Engineers. In 1958 he was appointed to the engineering board of studies, National Council for Technological Awards.

Mr. W. E. Bardgett, research manager in the research and development department of the United Steel Companies Ltd., has retired from this position, but remains with the department as a consultant. **Dr. K. J. Irvine,** at present deputy research manager, succeeds Mr. Bardgett with the title of metallurgical research manager.

Mr. Bardgett joined United Steel in 1933 as head of the metallurgical section, being appointed research manager in 1946. He was awarded the Sir Robert

Hadfield Medal of the Iron and Steel Institute in 1953 and is president of the Institution of Metallurgists for 1960-61.

Dr. Irvine was lecturer in metallurgy at Leeds University until being appointed head of the metallurgy section of United Steel's research and development department in 1954. He became deputy research manager in 1959.

At the last A.G.M. of the Sheffield Cutlery Manufacfacturers Association, **Mr. Ruben Viner,** managing director of the Viner Group of Companies, was unanimously re-elected president of the Association for the fourth year in succession.

Under the Association's constitution, a president can only hold office for three years in succession but, as a tribute to his work on behalf of the Association in the past three years, Mr. Viner was invited to stand again. To enable this to be done, the rule in question was temporarily suspended.

Dr. William Henry George Lake, O.B.E., has been appointed joint managing director (technical) of the Metals Division of I.C.I. in succession to Mr. St. J. Elstub. Dr. Lake, who is 45, took an honours degree and later a PH.D. degree at Birmingham University. He joined I.C.I. Dyestuffs Division in 1940 and was transferred to the research department of I.C.I. Metals Division three years later. Between 1943 and 1952 he was engaged in work on behalf of the Government's atomic energy project. It was this work which brought him the award of the O.B.E. in the 1952 New Year Honours.

Dr. Lake was appointed assistant research manager of I.C.I. Metals Division in 1952 and a year later took charge of the team appointed to construct and commission the commercial-scale titanium melting plant at Witton. He was appointed a director of I.C.I. Metals Division in 1957.

The appointment is announced of two new directors of I.C.I. Metals Division, **Mr. T. H. Gallie** (overseas) and **Mr. J. R. H. Crane** (copper products).

Mr. Gallie has been concerned with metal sales throughout his 25 years' service with the company and for the past two years has been metal sales manager, Midland Region. His appointment to the Metals Division board is as overseas director, a new post created to strengthen the sales effort in overseas markets and to co-ordinate the export activities of all Metals Division production units.

Mr. Crane, who is 37, joined I.C.I. Metals Division as a laboratory assistant in 1939 but quickly developed a bent for the technical side of metal production. For almost the whole of his I.C.I. service, which was interrupted by four years in the Royal Air Force, he has been concerned with the production of wrought metals—first of rolled copper and brass, more recently of titanium. After two years as titanium production manager, he was transferred in 1959 to Lightning Fasteners Ltd., Witton, as general manager.

He has now been appointed director in charge of copper products.

The Department of Scientific and Industrial Research announces two Scientific Attaché appointments today. One is an entirely new post of Scientific Attaché to the British Embassy in Tokyo to advise the British Ambassador on scientific matters and to report on Japanese scientific and technical development in the civil field. The other is the appointment of a successor to Mr. G. H. Greenhalgh, whose tour of duty as Scientific Attaché to the British Embassy in Stockholm ends soon.

Dr. Charles Manders, aged 54, has been selected to fill the Tokyo post. He will hold the rank of senior principal scientific officer and joins the Department of Scientific and Industrial Research from the Ministry of Defence.

The new Scientific Attaché in Stockholm will be **Mr. William Drury.** He joins the DSIR from the Royal Naval Scientific Service, where he is currently scientific assistant to Sir John Carroll, Deputy Controller (Research and Development). Mr. Drury, who is 43, will also hold the rank of senior principal scientific officer.

Mr. H. R. Brooker has joined the board of Johnson, Matthey & Co. Ltd. as a joint managing director of the company.

Mr. Brooker has hitherto been general sales manager and he will continue to be principally responsible for all the sales division of the company.

Mr. George Talbot has been appointed deputy managing director of Stein & Atkinson Ltd.

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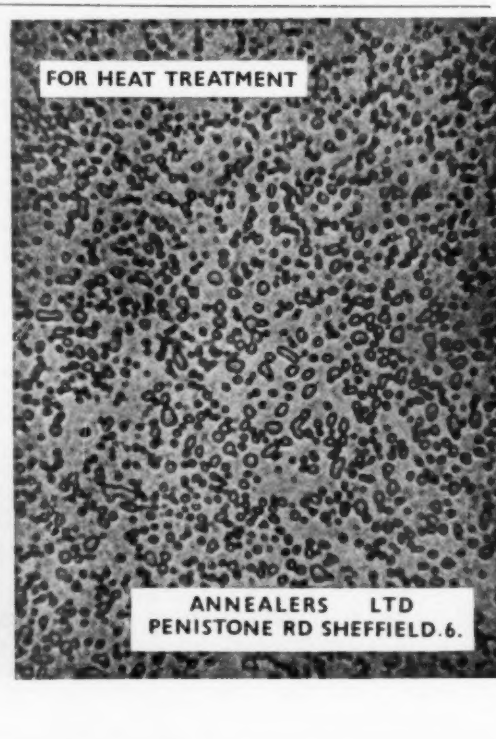
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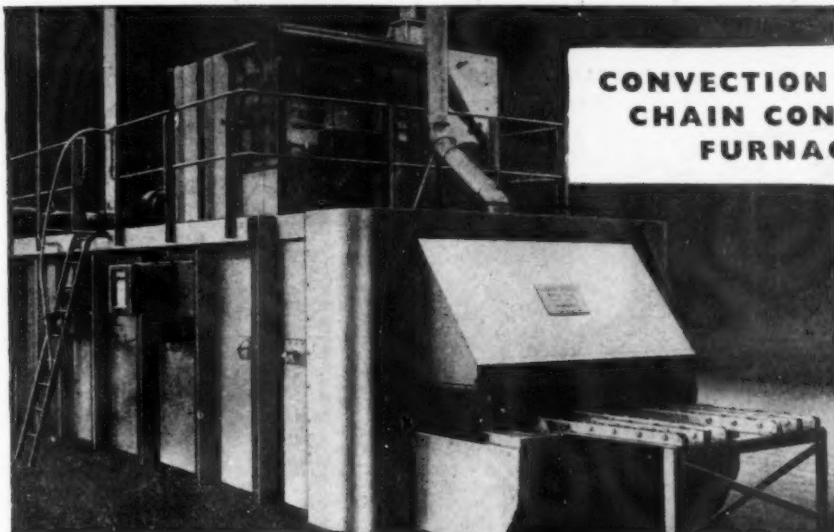

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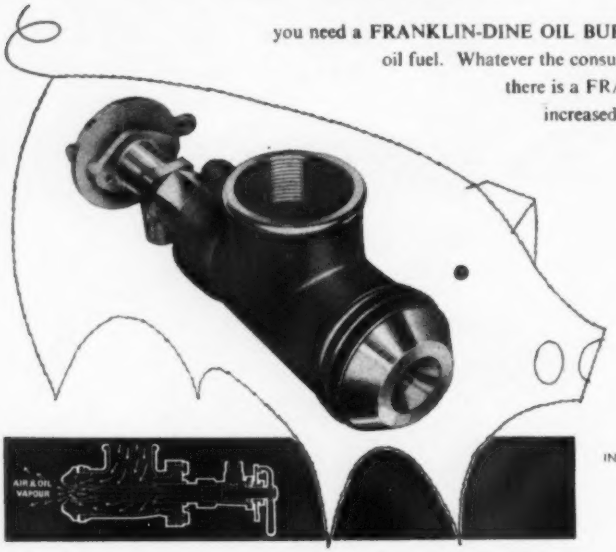

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